T.K. Lim

Edible Medicinal and Non-Medicinal Plants

Volume 9, Modified Stems, Roots, Bulbs

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Contents

Introduction

This book continues as volume nine of a multi-compendium on *Edible Medicinal and Non Medicinal Plants*. It covers such plants with edible modified storage subterranean stems (corms, rhizomes, stem tubers) and unmodified subterranean stem stolons, above-ground swollen stems and hypocotyls, storage roots (taproot, lateral roots, root tubers) and bulbs that are eaten as conventional or functional food as vegetables and spices, as herbal teas, and may provide a source of food additive or nutraceuticals. A list of such edible plant species from families: Acanthaceae to Zygophyllaceae are presented in a tabular form (Table 1) and 32 such edible species from the families Alismataceae, Amaryllidaceae, Apiaceae, Araceae, Araliaceae, Asparagaceae, Asteraceae, Basellaceae, Brassicaceae and Campanulaceae are covered in detail in separate chapters. Other such edible species in the families: Amaranthaceae, Cannaceae, Cibotiaceae, Convolvulaceae, Cyperaceae, Dioscoreaceae, Euphorbiaceae, Fabaceae, Iridaceae, Lamiaceae, Marantaceae, Nelumbonaceae, Nyctaginaceae, Nymphaeaceae, Onagraceae, Orchidaceae, Oxalidaceae, Piperaceae, Poaceae, Rubiaceae, Simaroubaceae, Solanaceae, Tropaeolaceae, Typhaceae and Zingiberaceae will be covered in detail in the next volume. Many plants with such edible plant parts that are better known for their edible fruits or flowers have been covered in earlier volumes and for those better known for other nonreproductive plant parts will be covered in latter volumes.

As in the preceding eight volumes, topics covered include taxonomy (botanical name and synonyms), common English and vernacular names, origin and distribution, agro-ecological requirements, edible plant part and uses, plant botany, nutritive and medicinal/pharmacological properties with up-to-date research findings, traditional medicinal uses, other non-edible uses and selected/cited references for further reading.

A corm or bulbotuber is defined as a short, vertical, swollen, underground plant stem that serves as a storage organ used by some plants to survive unfavourable adverse periods. It bears membranous or scaly leaves and buds. Some examples of plants with edible corms are found in *Amorphophallus* spp., *Colocasia esculenta* (taro), *Eleocharis dulcis* (Chinese water chestnut), *Sagittaria* spp. (arrowhead or wapato) and *Xanthosoma* spp. (cocoyam or tannia). Corms often give rise to many small secondary corms or cormlet called cormels at the end of very short stolons.

Rhizome is a modified subterranean stem of a plant that is usually found underground, producing roots and shoots. It is used by the plant as storage organ, and whole rhizome or pieces of the rhizome serve as vegetative propagules to give rise to new plants. Examples of plants with edible rhizomes include gingers (*Zingibe*r spp.), turmeric (*Cucurma longa*), greater galangal (*Alpinia galanga*), lesser galangal (*Alpinia officinarum*), sand ginger or kencur (*Kaempferia galanga*), lotus root (*Nelumbo nucifera*), *Typha* spp.,

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Table 1 Plants with edible modified stems, roots and bulbs

Scientific name	Family	Common/vernacular names	Edible part use	Reference
Abelmoschus crinitus Wall.	Malvaceae	Hairy Okra	Tuberous taproots are edible	Groen et al. (1996)
Abelmoschus ficulneus (L.) Wight & Arn.	Malvaceae	White Wild Musk Mallow, Native Rosella	Underground taproot is eaten	Cribb and Cribb (1987) and Facciola (1990)
Abelmoschus manihot (L.) Med.	Malvaceae	Sunset Muskmallow, Sunset Hibiscus, Hibiscus Manihot, Aibika; Qiu kui (Chinese)	Taproots are boiled with pork in broth	Hu (2005)
Abelmoschus moschatus Medik.	Malvaceae	Bush Carrot	Underground taproot is eaten	Cribb and Cribb (1982, 1987) and Facciola (1990)
Abronia latifolia Eschsch.	Nyctaginaceae	Yellow Sand Verbena	Root is edible	Yanovsky (1936) and Facciola (1990)
Abuta platyphylla, Mart. ex Eichler	Menispermaceae	Videira Silvestre, Uva Do Apa, Parreira Brava	Brazil (northeast): a flour is extracted from the root starch	De Castro (1952)
Acacia bidwillii Benth.	Fabaceae	Corkwood Wattle	Young roots are cooked as food by the aborigines	Cribb and Cribb (1982, 1987)
Acacia crassicarpa Benth.	Fabaceae	Northern Wattle, Thick-Podded Salwood, Brown Salwood, Papua New Guinea Red Wattle, Red Wattle	As above	Cribb and Cribb (1982, 1987)
Acacia holosericea G. Don	Fabaceae	Silver Leaf Wattle	As above	Cribb and Cribb (1987)
Achasma loroglossum (Gagnep) K. Larsen	Zingiberaceae	Karphul, Gandh Tora (Assamese)	Aromatic rhizomes are eaten fresh or with betel nut or as masticatory. Small bits are added in curries for flavour	Patiri and Borah (2007)
Acianthus collinus D.L. Jones = *Acianthus fornicatus* R. Br.	Orchidaceae	Mountain Giant Orchid	Tuber is edible	Harden (1993)
Acianthus apprimus D.L. Jones = *Acianthus fornicatus* R. Br.	Orchidaceae	Pixie Caps, Mosquito Orchid, Mayfly Orchids	Tuber is edible	Harden (1993)
Acianthus exsertus R. Br.	Orchidaceae	Mosquito Orchid	Tuber is edible	Harden (1993)
Acianthus fornicatus R. Br.	Orchidaceae	Pixie Caps, Mosquito Orchid, Mayfly Orchids	Tuber is edible	Harden (1993)
Acianthus pusillus D.L. Jones = *Acianthus exsertus* R. Br.	Orchidaceae	Gnat Orchid, Mosquito Orchid	Tuber is edible	Harden (1993)
Acianthus sp.	Orchidaceae	Pixie Caps	Tubers are eaten by aborigines	Cribb and Cribb (1987)
Aciphylla squarrosa J.R. Forst. & G. Forst.	Apiaceae	Common Speargrass	Roots are edible	Facciola (1990)

Aconitum carmichaelii Debeaux	Ranunculaceae	Sichuan Aconite, Bai Fu Pian (Chinese)	Young tubers are used as tonic in broth with chicken especially for the elderly	Hu (2005)
Acorus calamus L.	Araceae	Calamus, Sweet Flag, Sweet Myrtle, Myrtle Sedge, Sweet Root, Beewort	Starch-rich rhizome is peeled and washed to remove acrid element before consumption; rootstock is candied, chewed as ginger substitute and to sweeten the breath	Read (1946), Burkill (1966), Uphof (1968), Morton (1976), Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Acorus gramineus Aiton	Araceae	Grass-Leaved Sweet Flag, Japanese Sweet Flag, Japanese Rush	Rhizome after peeling and washing is eaten fried or oil roasted, also used as flavouring	Hedrick (1972), Tanaka (1976), and Facciola (1990)
Acrostichum speciosum Willd.	Pteridaceae	Mangrove Fern	Starch-rich underground stem is eaten	Cribb and Cribb (1987) and Low (1989)
Adansonia digitata L.	Malvaceae	Baobab, Dead-Rat Tree, Bottle Tree, Monkey-Bread Tree Baobab	Tuberous roots are edible	Facciola (1990), Sidibe and Williams (2002), and Lim (2012a)
Adansonia gregorii F. Muell.	Malvaceae	Baobab, Bottle Tree, Monkey Fruit Tree, Cream of Tartar Tree, Sour Gourd Tree and Upside-Down Tree	Tuberous roots are edible	Johnson et al. (2002, 2006) and Lim (2012a)
Adenochilus nortonii Fitzg.	Orchidaceae	Creeping Fairy Orchid	Tubers are edible	Harden (1993)
Adenophora polymorpha var. *latifolia* (Fisch.) Herder	Campanulaceae	Bluebell	In China, root is boiled in two changes of water and eaten	Read (1946)
Adenophora remotiflora (Siebold & Zucc.) Miq.	Campanulaceae	Panicled Lady Bells	As above	Read (1946)
Adenophora stricta Miq.	Campanulaceae	Sha Shen (Chinese), Ladybells	As above	Read (1946)
Adenophora tetraphylla (Thunb.) Fisch. = *Adenophora triphylla* (Thunb.) A. DC.	Campanulaceae	Ladybell Root, Nan Sha Shen (Chinese)	Fusiform taproot is dried, used with Chinese jujubes, lotus rhizome and pork chops with bones for soup	Hu (2005)
Adenophora triphylla (Thunb.) A.DC.	Campanulaceae	Ladybell Root	As above	Codex (2014)
Adenophora verticillata Fisch. = *Adenophora triphylla* (Thunb.) A.DC.	Campanulaceae	As above	As above	Read (1946) and Uphof (1968)
Adhatoda zeylanica Medik. = *Justicia adhatoda* L.	Acanthaceae	Jok An Kelok (Assamese)	Root is eaten in Karbi, Assam	Kar and Borthakur (2008)
Agave utahensis Engelm.	Asparagaceae	Utah Agave	Roots are edible	Gibbons and Tucker (1979) and Facciola (1990)

(continued)

Table 1 (continued)

Agropyron repens (L.) P. Beauv. = *Elymus repens* (L.) Gould	Poaceae	English Couch, Quick Grass	Roots are ground into a meal and used to make bread	Cribb and Cribb (1987)
Alisma plantago-aquatica L.	Alismataceae	European Water Plantain, Water Plantain, Deil's Spoons, Devil's Spoons	Roots are edible	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Allium altaicum Pall.	Amaryllidaceae	Altai Onion	Bulb is used as spice	Seidemann (2005)
Allium ampeloprasum cv. group Leek		Leek	Pseudostem/bulb is eaten, boiled, braised or blanched	Sulistiorini and van der Meer (1994)
Allium ampeloprasum L.	Amaryllidaceae	Leek	Pseudostem/bulb is eaten, boiled, braised or blanched and served with a white sauce or cheese dressing	Hu (2005), Seidemann (2005), and van Wyk (2006)
Allium angolense Baker = *Allium cepa* L.	Amaryllidaceae	African Onion, African Shallot	Bulb is used as spice	Seidemann (2005)
Allium angulosum L.	Amaryllidaceae	Edged Garlic	Bulb is used as spice	Seidemann (2005)
Allium ascalonium L.	Amaryllidaceae	Shallot	Bulbs are eaten	Hu (2005), Seidemann (2005), and Walter and Lebot (2007)
Allium canadense L.	Amaryllidaceae	Canada Onion, American Wild Onion	Bulb is used as spice	Seidemann (2005)
Allium carinatum L.	Amaryllidaceae	Keeled Garlic	Bulb is used as spice	Seidmann (2005)
Allium cepa L.	Amaryllidaceae	Onion, Common Onion	Bulbs are eaten chopped, sliced dice, fresh or cooked, sautéed, stewed, fried and roasted or in soups, sauces, curries, sauces or with meat dishes	Phillips and Rix (1993), Hu (2005), Seidemann (2005), van Wyk (2006), Walter and Lebot (2007), and Santich et al. (2008)
Allium cepa L. cv. group Common Onion	Amaryllidaceae	Onion, Common Onion	As above	Van der meer and Leong (1994)
Allium cepa L. cv. group Aggregatum	Amaryllidaceae	Shallots, Multiplier Onion, Echalote	Bulb is used as food, spice and seasoning	Permadi and van der Meer (1994)
Allium chinense G. Don	Amaryllidaceae	Chinese Shallot, Rakyok Lokyo	Bulb is eaten, pickled or served as salted sour preserves or sweets	van der meer and Agustina (1994), Hu (2005), and Seidemann (2005)
Allium chrysanthum Regel	Amaryllidaceae	Wild Onion, Tain Cong (Chinese)	Whole plant including the oblong cylindrical bulb is eaten	Hu (2005)
Allium consanguineum Kunth	Amaryllidaceae	None	Bulb is used as spice	Seidemann (2005)
Allium fistulosum L.	Amaryllidaceae	Welsh Onion, Bunching Onion, Scallion	Pseudostem and leaves are used in Asian cooking, in salads, stir-fries, noodles, soups, spring rolls and salads	Phillips and Rix (1993), Oyen and Soenoeadji (1994), Hu (2005), van Wyk (2006), and Santich et al. (2008)

Allium hookeri Thwaites	Amaryllidaceae	Broad-Leaved Leek, Kuan Ye Jiu (Chinese)	Fleshy roots are eaten in Yunnan	Hu (2005)
Allium ledebourianum Schult. & Schult.f.	Amaryllidaceae	Tartar Scallion, Xiao Cong (Chinese)	Whole plant including ovoid bulb is eaten	Hu (2005)
Allium lineare L.	Amaryllidaceae	Northern Leek, Thread Onion, Bei Jiu (Chinese)	Young plant with small bulb is eaten	Hu (2005)
Allium macrostemon Bunge	Amaryllidaceae	Chinese Field Garlic, Xiao Suan (Chinese)	Young plant with fleshy subglobose or ovoid bulb is eaten	Hu (2005)
Allium moly L.	Amaryllidaceae	Lily Leek, Moly, Yellow Onion	Bulb is used as spice	Seidemann (2005)
Allium mongolicum Regel	Amaryllidaceae	Mongolian Leek, She Cong (Chinese)	Young plant with bulb is eaten	Hu (2005)
Allium neapolitanum Cirillo	Amaryllidaceae	Daffodil Garlic, Naples Garlic, False Garlic, Neapolitan Garlic	Bulb is used as spice/condiment	Seidemann (2005)
Allium obliquum L.	Amaryllidaceae	Oblique Garlic	Bulb is used as spice	Seidemann (2005)
Allium oleraceum L.	Amaryllidaceae	Field Garlic	Bulb is used as spice	Seidemann (2005)
Allium oschaninii O. Fedtsch.	Amaryllidaceae	Oschanin-Zwiebel (German)	Bulb is used as spice	Seidemann (2005)
Allium paradoxum (M. Bieb.) G. Don	Amaryllidaceae	Few-Flowered Leek	Bulb is used as spice	Seidemann (2005)
Allium porrum L.	Amaryllidaceae	Leek	When braised or slow roasted, the white bulb takes on a buttery texture, excellent additions to meat and chicken, also excellent in stir-fries with seafood and in soups	Phillips and Rix (1993), Seidemann (2005), and Santich et al. (2008)
Allium x proliferum (Moench) Schrad. ex Willd.	Amaryllidaceae	Egyptians, Catawissa Onion, Top Onion, Tree Onion	Bulb is used as spice	Seidemann (2005)
Allium pskemense B. Fedtsch.	Amaryllidaceae	Pskemense-Zwiebel (German)	Bulb is used as spice	Seidemann (2005)
Allium sativum L.	Amaryllidaceae	Garlic	Bulbs are eaten raw in dressings, salads, marinades and sauces. Pickled garlic is used as condiments and as ingredient for other dishes. Cooked garlic is used as flavouring agent in soups, stir-fries, stews, vegetables, meat and seafood dishes and noodles	Phillips and Rix (1993), van der Meer and Permadi (1994), Hu (2005), van Wyk (2006), Walter and Lebot (2007), and Santich et al. (2008)

(continued)

Table 1 (continued)

Allium sativum L. var. *ophioscorodon* (Link) Döll = *Allium sativum* L.	Amaryllidaceae	Rocambole, Giant Garlic, Serpent Garlic	Bulb is used as spice	Seidemann (2005)
Allium schoenoprasum L.	Amaryllidaceae	Garden Chives	Narrow bulbs and leaves are edible	Phillips and Rix (1993) and van Wyk (2006)
Allium senescens L.	Amaryllidaceae	German Garlic	Young bulb and leaves are eaten	Hu (2005)
Allium tricoccum Aiton	Amaryllidaceae	Wild Leek	Young bulbs are sweet and flavoursome, eaten raw or cooked by native Indians	Saunders (1920)
Allium tuberosum Rottler ex Sprengel	Amaryllidaceae	Chinese Leek	Insignificant small bulbs are seldom used; leaves and flower buds and stalks are commonly used	Phillips and Rix (1993), van der meer (1994), Hu (2005), and van Wyk (2006)
Allium victorialis L.	Amaryllidaceae	Wild Onion, Ge Cong (Chinese)	Leaves and cylindrical bulbs are eaten	Hu (2005)
Alocasia acuminata Schott	Araceae	Kochu (Assamese), Thaso (Bodo), Ange (Mishing)	Young shoots, tender leaves and corms are eaten, cooked mostly with acidic fruit	Patiri and Borah (2007)
Alocasia cucullata (Lour.) G. Don	Araceae	Panchamukhi Kochu, Boga Kachu (Assamese)	Corm, cormel and stem are eaten as vegetable. Chips can also be prepared from it	Burkill (1966), Groen et al. (1996), and Patiri and Borah (2007)
Alocasia fornicata (Roxb.) Schott	Araceae	Bez Kachu, Bees Kachu (Assamese and Bengali)	Petioles and corms are eaten cooked with much acidic fruit like 'Thekera' or tamarind	Patiri and Borah (2007)
Alocasia indica (Lour.) Spach = *Alocasia macrorrhiza* (L.) G. Don	Araceae	Giant Alocasia Kachu (Assamese and Bengali)	Corm and shoots are eaten cooked by many communities with acidic fruits in Assam. It can also be preserved by slicing and drying for later use	Patiri and Borah (2007) and Codex (2014)
Alocasia macrorrhiza (L.) G. Don	Araceae	Alocasia, Cunjevoi, Henchala (Assamese)	Stem and corm are baked and pounded by aborigines in Australia. Corm is eaten in Karbi, Assam	Cribb and Cribb (1982, 1987), Low (1989), Phillips and Rix (1993), Groen et al. (1996), Walter and Lebot (2007), Kar and Borthakur (2008), and Codex (2014)
Alocasia portei Schott	Araceae	Elephant Ear, Badiang (Bikol, Philippines)	Corm, cormel and petiole are eaten as vegetable	Groen et al. (1996)
Alpinia calcarata (Haw.) Roscoe	Zingiberaceae	Indian Ginger, Snap Ginger	Rhizome is used as galangal substitute	Seidemann (2005)

Alpinia caerula (R. Br.) Benth.	Zingiberaceae	Australian Blue Ginger, Native Ginger	Young rhizome is eaten raw or cooked	Cribb and Cribb (1987), Facciola (1990), Seidemann (2005)
Alpinia conchigera Griff.	Zingiberaceae	Lesser Alpinia, Mussel Galangal; Lengkuas Ranting (Malay); Riềng Rừng (Vietnamese)	Rhizome is used as food flavouring and flavouring of alcoholic drinks	Perry (1980), Wong et al. (2005), Seidemann (2005), and Faridah et al. (2010)
Alpinia galanga (Linn) Willd.	Zingiberaceae	Galangal, Greater Galangal; Languas, Lenguas (Indonesia, Malaysia); Phrikgnek (Assamese); Riềng Nếp (Vietnamese)	Rhizomes are used as spice fresh or cooked in everyday cooking, in curries and meat dishes. Essential oil extract from rhizome is used to flavour liqueurs, ice cream, pastry, etc. Rhizome is eaten in Karbi, Assam, India. In Indonesia, young rhizomes are sliced and used in side dishes as sayur or sambal, and the juice is used in the preparation of *dengdeng*	Watt (1908), Ochse and van den Brink (1980), Scheffer and Jansen (1999), Seidemann (2005), van Wyk (2006), and Kar and Borthakur (2008)
Alpinia latilabris Ridl.	Zingiberaceae	Ry (Vietnamese)	Rhizome is used as food flavouring. In Vietnam, bitter rhizome is used as spice	Wong et al. (2005) and Tanaka and Nguyen (2007)
Alpinia malaccensis (Burm.f.) Roscoe	Zingiberaceae	Malacca Galangal; Riềng Malacca (Vietnamese)	Rhizome is used as spice	Burkill (1966), Kashio and Johnson (2001), Seidemann (2005), and Sirat et al. (2011)
Alpinia nigra (Gaertn.) Burtt	Zingiberaceae	Tora (Assamese), Tareng (Mishing), Tharai (Bodo)	Young shoots and rhizomes are eaten either raw or cooked	Patiri and Borah (2007)
Alpinia officinarum Hance	Zingiberaceae	Lesser Galangal, Smaller Galangal, Chinese Ginger; Riềng Thuoc (Vietnamese)	Rhizome is used as spice for flavouring	Ly et al. (2003) and Seidemann (2005)
Alpinia zerumbet (Pers.) B.L. Burtt & R.M. Sm.	Zingiberaceae	Bright Ginger, Pink Porcelain Lily, Light Ginger; Riềng Đẹp, Riềng ấm (Vietnamese)	Rhizome is edible, used as spice for flavouring	Seidemann (2005)
Alstonia acuminata Miq. = *Alstonia macrophylla* Wall. ex G. Don	Apocynaceae	Ajooras, Poole Batoo	Root is used to add bitterness to palm toddy	Burkill (1966) and Seidemann (2005)
Althaea officinalis L.	Malvaceae	Marshmallow, Marsh Mallow, Common Marshmallow	Roots are boiled, sliced and fried with onion. Root decoction is used as substitute for egg white in meringue or chiffon pies	Uphof (1968), Hedrick (1972), Gibbons and Tucker (1979), and Facciola (1990)

(continued)

Table 1 (continued)

Ammobroma sonorae Torr. ex A. Gray = *Pholisma sonorae* (Torr. ex A. Gray) Yatsk.	Boraginaceae	Sand Food, Camote De Los Medanos	The subterranean stem is tender, juicy and sweet – a refreshing and luscious morsel, meat and drink in one	Saunders (1920)
Amorphophallus campanulatus Decne. = *Amorphophallus paeoniifolius* (Dennst.) Nicolson	Araceae	Elephant Foot Yam; Kurruna Kalungu (Tamil); Konda, Muncha Kunda (Telugu)	Corms are eaten after being cooked or baked in India (Madras Presidency)	Shortt (1887–1888), Burkill (1966), Facciola (1990), Phillips and Rix (1993), Walter and Lebot (2007), and Codex (2014)
Amorphophallus aphyllus (Hook.) Hutch.	Araceae	Bombole (Kissi, Guinea), Baga (Mandingo–Bambara, Mali)	Sudan (western): corms are dried and then boiled to remove the acrid element, eaten in times of scarcity by the Wolof people of the Cayor region	Irvine (1952)
Amorphophallus bulbifer (Roxb.) Blume	Araceae	Hen Salku (Assamese)	Corm is eaten in Karbi, Assam	Kar and Borthakur (2008)
Amorphophallus consimilis Blume	Araceae	Apaty (Basari), Gingi (Bedik)	In Senegal and Guinea, corms are eaten	Ferry et al. (1974)
Amorphophallus dracontioides (Engl.) N.E. Br.	Araceae	Kinciyar (Hausa)	Africa (west): corms are eaten after being cut up, repeatedly washed and boiled for 1 or 2 days. Nigeria (Kano State, northern): tuber is eaten, requires 2-day boiling to detoxify	Irvine (1952) and Mortimore (1989)
Amorphophallus galbra F.M. Bailey	Araceae	Cheeky Yam, Queensland Yellow Lily Yam, Sweet Snakeskin Lily	Corms are grated, pounded, soaked and baked	Cribb and Cribb (1987) and Low (1989)
Amorphophallus glabra F.M. Bailey = *Amorphophallus galbra* F.M. Bailey	Araceae	As above	Corms are eaten	Roth (1901)
Amorphophallus konjac K. Koch	Araceae	Elephant Foot Yam	Corms are eaten	Jansen et al. (1996) and Codex (2014)
Amorphophallus mairei H. Lev. = *Amorphophallus konjac* K. Koch	Araceae	Elephant Foot Yam	Corms are eaten in Yunnan and Laos	Hu (2005)
Amorphophallus muelleri Blume	Araceae	Elephant Foot Yam	Corms are edible	Jansen et al. (1996)
Amorphophallus paeoniifolius (Dennst.) Nicolson	Araceae	Elephant Foot Yam	Corms are edible	Wightman and Andrews (1989, 1991), Jansen et al. (1996), and Codex (2014)
Amorphophallus rivieri Durand ex Carrière = *Amorphophallus konjac* K. Koch	Araceae	Devil's Tongue, Leopard Palm, Snake Palm, Mo Yu (Chinese)	China: corm is ground and processed into a rich starch used for making a jelly-like food	Hu (2005)

Amorphophallus sylvaticus Kunth	Araceae	Elephant Foot Yam	In India (Deccan), corms and leaves are eaten	Watt (1908)
Amorphophallus variabilis Blume	Araceae	Elephant Foot Yam	Corms are eaten	Cribb and Cribb (1987), Burkill (1966), Facciola (1990), and Jansen et al. (1996)
Ampelocissus acetosa (F. Muell.) Planch.	Vitaceae	Native Grape	Underground root is eaten	Cribb and Cribb (1987)
Aneilema siliculosum R. Br.	Commelinaceae	Djnj (Abor., Australia)	Roots are eaten raw and roasted	Cribb and Cribb (1987)
Anemarrhena asphodeloides Bunge	Asparagaceae	Zhi Mu (Chinese)	China: root is eaten	Read (1946)
Angelica atropurpurea L.	Apiaceae	Great Angelica, Purple-Stem Angelica	Roots are candied	Morton (1976), Fernald et al. (1958), and Facciola (1990)
Angelica sinensis (Oliv.) Diels	Apiaceae	Chinese Angelica, Dang Gui (Chinese)	Root slices are used in broth, soups with Chinese dates, goji berries, laminaria and chicken or pork as health food especially for women	Hu (2005)
Angiopteris esculenta Ching	Marattiaceae	Shi Yong Lian Zuo Jue (Chinese)	Starch extracted from rhizome is made into cakes or mixed with other foods	Cui (1998), Dai et al. (2003), and Cao et al. (2007)
Angiopteris fokiensis Hieron.	Marattiaceae	Fu Jian Lian Zuo Jue (Chinese)	As above	Cui (1998), Dai et al. (2003), Cao et al. (2007), and Yun et al. (2009a)
Anigozanthos flavidus DC.	Haemodoraceae	Kangaroo Paw	Rhizomes are edible	Cribb and Cribb (1987)
Anigozanthos spp.	Haemodoraceae	Kangaroo Paws	Rhizomes are edible	Cribb and Cribb (1987) and Low (1989)
Anredera baselloides (Kunth) Baill.	Basellaceae	Madeira Vine, Luo Kui Shu (Chinese)	Fresh tubers are eaten	Hu (2005) and Codex (2014)
Anredera cordifolia (Ten.) Steenis	Basellaceae	Madeira Vine, Lamb's Tail	Tubers are eaten boiled like potatoes	Uphof (1968), Tanaka (1976), Cribb and Cribb (1987), Facciola (1990), and Codex (2014)
Anthriscus cerefolium (L.) Hoffm.	Apiaceae	Chervil, Garden Chervil	Roots are eaten	Hedrick (1972), Morton (1976), and Facciola (1990)
Anthriscus nemorosa (M. Bieb.) Spreng.	Apiaceae	Woodland Chervil, Lin Di-E-Shen (Chinese)	Roots are used as pickles by Chinese-Koreans	Hu (2005)
Anthriscus sylvestris (L.) Hoffm.	Apiaceae	Cow Parsley, Wild Chervil, Wild Beaked Parsley	Roots are eaten	Facciola (1990)

(continued)

Table 1 (continued)

Antigonon leptopus (Hook. & Arm.)	Polygonaceae	Coral Vine, Honolulu Creeper, Mexican Creeper, Bride's Tears, Chain-Of-Love, Hearts On A Chain, Love-Vine	Tubers are cooked and eaten	Uphof (1968), Williams (1981), Pongpangan and Poobrasert (1985), Facciola (1990), and Lim (2014)
Antiotrema dunnianum (Diels) Handel-Mazz.	Boraginaceae	Chang Rui Ban Zhong Cao (Chinese)	Roots are eaten by mountain people in Yunnan	Hu (2005)
Apios americana Medik.	Fabaceae (Leguminosae)	American Potato Bean	Tuberous roots are eaten raw or cooked	Facciola (1990), Phillips and Rix (1993), and Codex (2014)
Apios fortunei Maxim.	Fabaceae	Potato Bean, Groundnut	Thick tubers are eaten as emergency food in China	Read (1946) and Hu (2005)
Apios tuberosa Moench = *Apios americana* Medik.	Fabaceae	Groundnut, Wild Bean, Potato Bean, American Potato Bean, Indian Potato	Starchy tuber is eaten	Saunders (1920)
Apium graveolens Rapaceum Group	Apiaceae	Celeriac	Roots are sliced or grated and eaten raw in salads, braised, pureed, marinated, baked, mashed, cooked as vegetable and used in stews, fritters, soups and stuffings	Uphof (1968), Hedrick (1972), Halpin (1978), Facciola (1990), and Santich et al. (2008)
Apium graveolens L. var. *rapaceum* (Mill.) Gaudin	Apiaceae	Celeriac	As above	Codex (2014)
Aplectrum hyemale (Muhl. ex Willd.) Nutt.	Orchidaceae	Putty Root, Adam and Eve	Corm is boiled served with butter	Facciola (1990)
Aponogeton distachyos L.f.	Aponogetonaceae	Cape Asparagus, Water Onion, Water Hawthorn	Starchy root is eaten roasted in southern Africa	Hedrick (1972), Fox et al. (1982), and Facciola (1990)
Aponogeton elongatus F. Muell. ex Benth.	Aponogetonaceae	Queensland Lace Plant	Tuber is eaten cooked	Cribb and Cribb (1987)
Aponogeton fenestralis (Pers.) Hook.f. = *Aponogeton madagascariensis* (Mirb.) H. Bruggen	Aponogetonaceae	Madagascar Lace Leaf	Starchy tuber is eaten	Burkill (1966)
Aponogeton lakhonensis A. Camus	Aponogetonaceae	Sbai Mung (Kampuchean), Phakkhuap (Thai)	Starchy tuberous rhizomes are eaten during famine	Groen et al. (1996)
Aponogeton monostachyon L.f. = *Aponogeton natans* (L.) Engl. & K. Krause	Aponogetonaceae	Kotee Kalungu (Tamil), Nama (Telugu)	In India (Madras Presidency), tubers are eaten after boiling	Shortt (1887–1888)

Aponogeton queenslandicus H. Bruggen	Aponogetonaceae	Laceleaf	Tuber is cooked	Cribb and Cribb (1987)
Aponogeton undulatus Roxb.	Aponogetonaceae	Undulated Leaf *Aponogeton*	Starchy tuberous rhizomes are eaten during famine	Groen et al. (1996)
Aralia cordata Thunb.	Araliaceae	Udo, Japanese Spikenard, Mountain Asparagus, Tu Dang Gui (Chinese)	Roots are eaten as parsnips	Hu (2005)
Aralia racemosa L.	Araliaceae	American Spikenard, Petty Morel	Roots are used as an ingredient of root beer. Menomonie Indians used roots in a dish with wild onion, wild gooseberry and sugar	Fernald et al. (1958) and Facciola (1990)
Araucaria bidwillii Hook.	Araucariaceae	Bunya Pine	Germinated seed produces an underground earthnut which has a coconut flavour	Menninger (1977), Cribb and Cribb (1987), and Facciola (1990)
Arctium lappa L.	Asteraceae	Great Burdock, Edible Burdock, Burdock, Gobo	China: roots and leaves are eaten. It may be eaten raw. France: starch of root is recommended for extending bread flour, after removal of bitter element. Grated root is added to soups and stews; slices or slivers are used in stir-fries	Read (1946), Facciola (1990), Phillips and Rix (1993), Van den Bergh (1994), Hu (2005), van Wyk (2006), and Codex (2014)
Argyrolobium marginatum Bolus	Fabaceae	Izi Ntondo (Zulu)	In Zululand (Ubombo district), roots are eaten cooked or uncooked	Hely-Hutchinson (1898)
Arisaema curvatum (Roxb.) Kunth = *Arisaema tortuosum* (Wall.) Schott	Araceae	Curved-Hood Cobra Lily	India: corms are eaten	Watt (1908)
Arisaema concinnum Schott	Araceae	Chinese Cobra Lily	Starchy corms are eaten	Burkill (1966) and Groen et al. 1996
Arisaema murrayi (J. Graham) Hook.	Araceae	Baddha, Dhudhda, Diwa (Bombay)	In India (Bombay Presidency), corms are cooked in water and mixed with salt and chilli peppers	Gammie (1902)
Arisaema speciosum (Wall.) Mart.	Araceae	Cobra Lily	Starchy corms are eaten	Burkill (1966) and Groen et al. (1996)
Arisaema tortuosum (Wall.) Schott	Araceae	Curved-Hood Cobra Lily	India: corms are cooked in water and mixed with salt and chilli peppers. Corms are eaten in Karbi, Assam	Gammie (1902) and Kar and Borthakur (2008)

(continued)

Table 1 (continued)

Arisaema triphyllum Torr. = *Arisaema triphyllum* (L.) Schott	Araceae	Jack-in-the-Pulpit	Small, turnip-shaped corm is eaten after thorough processing	Saunders (1920) and Facciola (1990)
Arisarum simorrhinum Durieu	Araceae	Ouden El-Fil, Cebot El-Ghoula, Kelb El-Beqouqa, Rejel El Begra (Berber); Tioughda, Tiqqenousine, Quaba, Abbouq, Taourza, Airni, Hierni, Idjened Tikilmout (Arabic, Tunisia)	In Tunisia, rootstock is gathered, dried, pulverised and mixed with the flour of barley or wheat	Bouquet (1939)
Arisarum vulgare O. Targ. Tozz.	Araceae	Friar's Cowl	As above	Bouquet (1939)
Aristolochia rotunda L.	Aristolochiaceae	Snakeroot, Smearwort, Round-Leaved Birthwort, English Mercury, Mercury Goosefoot	In France, starch of root is recommended as a famine food for extending bread flour, after removal of acrid elements	Parmentier (1781) (cited by Freedman 2009)
Armoracia rusticana P. Gaertn., B. Mey. & Scherb.	Brassicaceae	Horseradish	Roots with sharp mustard flavour, used as condiment with fish, sausages, poached chicken, egg salad, potato salad, dips, mustards, relishes, sauces, marinades, salad dressings and drinks, go well with beetroots, also dried, ground and mixed with vinegar, milk and seasoning to make horseradish sauce often used with beef	Facciola (1990), Phillips and Rix (1993), Nicols and Jansen (1999), Hu (2005), van Wyk (2006), Santich et al. (2008), and Codex (2014)
Arracacia xanthorrhiza Bancroft	Apiaceae	Arracacha, White Carrot, Peruvian Parsnip	Secondary tuber, starchy and sweet, is eaten boiled or fried	Facciola (1990), Groen et al. (1996), Hermann and Heller (1997), and Codex (2014)
Artemisa brachyloba Franch.	Asteraceae	Mongolian Sagebrush, Yan Hao (Chinese)	Roots are used in tea in Inner Mongolia	Hu (2005)
Arthropodium milleflorum (Dc.) J.F. Macbr.	Asparagaceae	Pale Vanilla Lily	Sweet–bitter tubers are eaten by aborigines	Cribb and Cribb (1987), Low (1991), and Harden (1993)
Arthropodium minus R. Br.	Asparagaceae	Vanilla Lilies	As above	Low (1991)
Arum dracunculus L. = *Dracunculus vulgaris* Schott	Araceae	Dragon Arum	France: starch of root is recommended as a famine food for extending bread flour, after removal of acrid element	Parmentier (1781) (cited by Freedman 2009)
Arum incurvatum Lam. = *Arisarum vulgare* subsp. *vulgare*	Araceae	Friar's Cowl, Larus	France: starch of root is recommended as a famine food for extending bread flour, after removal of acrid element	Parmentier (1781) (cited by Freedman 2009)

Arum italicum Mill.	Araceae	Italian Arum	Eaten in Tunisia (as for *Arisarum simorrhinum*)	Bouquet (1939)
Arum lyratum Roxb. = *Amorphophallus lyratus* (Roxb.) Kunth	Araceae	Kondai Rakis (Tamil), Konda Rakis (Telugu)	India (Madras Presidency): roots are eaten after careful boiling	Shortt (1887–1888) (cited by Freedman 2009)
Arum maculatum L.	Araceae	Snakeshead, Adder's Root, Arum, Wild Arum	Tunisia: as for *Arisarum simorrhinum*	Bouquet (1939)
Arum vulgare Lam. = *Arum maculatum* L.	Araceae	As above	France: starch of root is recommended as a famine food for extending bread flour, after removal of acrid element	Parmentier (1781) (cited by Freedman 2009)
Asarum canadense L.	Aristolochiaceae	Woodland Ginger, Ginger Root, Heart Snakeroot, Indian Ginger, American Wild Ginger	Rootstock is used as flavouring, boiled in syrup to form candied wild ginger. Syrup is used on ice cream and other desserts	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Asarum caudatum Lindl.	Aristolochiaceae	Long-Tailed Wild Ginger	Rootstock is used as ginger substitute	Uphof (1968) and Facciola 1990
Asclepias speciosa Torr.	Apocynaceae	Showy Milkweed	Roots are edible cooked	Fernald et al. (1958), Harrington (1974), and Facciola (1990)
Asclepias tuberosa L.	Apocynaceae	Butterfly Weed, Canada Root, Chieger Flower, Chiggerflower, Fluxroot, Indian Paintbrush	Tubers are said to be edible; some say they are poisonous	Yanovsky (1936), Hedrick (1972), Fernald et al. (1958), Harrington (1974), and Facciola (1990)
Asparagus cochinchinensis (Lour.) Merr.	Asparagaceae	Chinese Asparagus Root, Tumpeang (Kampuchean)	Tubers are eaten candied	Tanaka (1976), Facciola (1990), and Groen et al. (1996)
Asparagus pauli-guilelmi Solms-Laub. = *Asparagus flagellaris* (Kunth) Baker	Asparagaceae	Hyena Thorn, Gi'e Fowru (Fulade)	Africa (west): the tubers of this wild variety are boiled and then eaten	Irvine (1952) and Uphof (1968)
Asparagus racemosus Willd.	Asparagaceae	Shatavari, Wild Asparagus, Sparrow Grass	India (Rajasthan, western): fasciculated roots are eaten as vegetable; tuberous roots are eaten candied in Indonesia and made into conserve in India	Gupta (1962), Gupta and Kanodia (1968a, b), and Groen et al. (1996)
Asparagus sarmentosus L.	Asparagaceae	Challa-Gaddalu, Kilavari, Pappakilangu (India)	Fleshy roots are eaten in India and Sri Lanka. In China they are candied	Watt (1908), Hedrick (1972), and Facciola (1990)
Asphodeline lutea (L.) Rchb.	Xanthorrhoeaceae	Asphodel, Flower of the Dead	Roots are roasted and eaten like potatoes	Hedrick (1972) and Facciola (1990)

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Table 1 (continued)

Asphodelus albus Mill.	Xanthorrhoeaceae	White Asphodel	In France, root is recommended as a famine food. After cooking and reducing to a pulp, it is suggested it be blended into a confection with barley and buckwheat flour	Parmentier (1781) (cited by Freedman 2009)
Asphodelus fistulosus L.	Xanthorrhoeaceae	Onion Weed, Pink Asphodel	France: root is recommended as a famine food. Prepared as above. India: tubers are eaten	Parmentier (1781) (cited by Freedman 2009); WATT
Asplenium bulbiferum G. Forst.	Aspleniaceae	Hen and Chicken Fern, Pikopiko	Roots are eaten	Kunkel (1984) and Facciola (1990)
Asplenium unilaterale Lam.	Aspleniaceae	Pamohe	Rhizome is used fresh in snacks and salads	Yun et al. (2009b)
Astragalus fraxinifolius DC.	Fabaceae	Astragal Yasenelistnyi (Russian)	Starch of root is recommended as a famine food for extending bread flour, after removal of bitter element	Parmentier (1781) (cited by Freedman 2009)
Astragalus membranaceus (Fisch.) Bunge = *Astragalus propinquus* Schischkin	Fabaceae	Astragalus, Huangchoy (Chinese)	Dried root slices are used in combination with *Codonopsis* (dang shen) goji berries for a tonic soup with spare ribs	Hu (2005)
Atamasco atamasco (L.) Greene = *Zephyranthes atamasco* (L.) Herb.	Amaryllidaceae	*Atamasco* Lily, Rain Lily, Zephyr Lily	In North America, bulbous roots are eaten by Creek tribe in times of scarcity	Yanovsky (1936) and Hedrick (1972)
Athamanta sicula L.	Apiaceae	Spignel; Spaccapietre (Sicilian)	Roots are eaten	Facciola (1990)
Athyrium brevifrons Nakai ex Kitag.	Athyriaceae		Rhizome starch is used for cakes and noodles	Freedman (2009), Fox et al. (1982), and Gade (1975)
Athyrium filix-femina (L.) Roth	Athyriaceae	Lady Fern	Underground rootstock and stem are eaten after being peeled and roasting, or starch is extracted for making pastries, also used for wine making	Schofield (2003)
Atylosia reticulata (Dryand.) Taubert ex Ewart & Davies = *Cantharospermum reticulatum* (Dryand.) Taubert ex Ewart & Davies	Fabaceae	Not found (NF)	Roots are roasted	Cribb and Cribb (1987)
Balsamorhiza hookeri (Hook.) Nutt.	Asteraceae	Balsam Root, Hooker's Balsamroot, Hairy Balsamroot	Roots are eaten raw or cooked	Yanovsky (1936), Hedrick (1972), and Facciola (1990)

Balsamorhiza sagittata (Pursh) Nutt.	Asteraceae	Oregon Sunflower, Arrowleaf Balsamroot	Roots are eaten raw or cooked, roasted or used as coffee substitute	Yanovsky (1936), Hedrick (1972), Kunkel (1984), and Facciola (1990)
Bambusa pallida Munro	Poaceae	Mokal Bah (Assamese); Mai Phiu, Phai Song Kham (Thai)	Young rhizomes are eaten as vegetable after processing	Patiri and Borah (2007)
Bambusa tulda Roxb.	Poaceae	Spineless Indian Bamboo, Calcutta Cane; Jati Bah (Assamese)	As above	Patiri and Borah (2007)
Bauhinia hupehana Craib = *Bauhinia glauca* subsp. *hupehana* (Craib) T. Chen	Fabaceae	Shen Zi Ye, Hubei Yang Ti Jia (Chinese)	Root and stem are stewed with pro kidneys and intestines or cooked with pork as special health food in Huber and Sichuan	Hu (2005)
Begonia fagoproides DC.	Begoniaceae	Anchan Karay (Quechua)	Peru (Vilcanota Valley): rhizome is used	Gade (1975)
Beta vulgaris Cicla Group	Amaranthaceae	Swiss Chard, Spinach Beet, Foliage Beet, Seakale Beet	Some cultivars of Swiss chard have edible root	Facciola (1990)
Beta vulgaris cv. Crassa Group	Amaranthaceae	Beet, Beet Root, Sugar Beet, Mungel Wurzel	Globose root is boiled or cooked as vegetables. Fermented beetroot juice is commercially available. Sugar beets are source of sugar, syrup and molasses	Larkcom (1984) and Facciola (1990)
Beta vulgaris cv. Group Garden Beet	Amaranthaceae	Beet Root, Garden Beet, Field Beet	As above	Oyen and Soenoeadji (1994)
Beta vulgaris cv. Group Spinach Beet	Amaranthaceae	Foliage Beet, Leaf Beet	As above	Oyen and Soenoeadji (1994)
Beta vulgaris L.	Amaranthaceae	Beet, Beetroot, Garden Beet	Globose root is boiled or cooked as vegetables	Oyen and Soenoeadji (1994)
Beta vulgaris L. var. *saccharifera* = *Beta vulgaris* L.	Amaranthaceae	Sugar Beet	Swollen, fleshy globose root is processed for sugar	Codex (2014)
Beta vulgaris L. var. *conditiva* = *Beta vulgaris* L.	Amaranthaceae	Beetroot	As above	Codex (2014)
Beta vulgaris var. *esculenta* = *Beta vulgaris* L.	Amaranthaceae	Beet Root, Garden Beet, Field Beet	Peeled and cooked before eating, can be roasted, added to soups and pickled. Pickled beet roots are used in salads as side dish or as a condiment; slices are used in hamburgers	Facciola (1990), van Wyk (2006), Santich et al. (2008), and Phillips and Rix (1993)

(continued)

Table 1 (continued)

Beta vulgaris var. *rapa* Dumont	Amaranthaceae	Garden Beet, Beet Root	As above	Hu (2005)
Beta vulgaris var. *vulgaris* = *Beta vulgaris* L.	Amaranthaceae	Beet, Garden Beet	Swollen, fleshy globose root is processed for sugar	Phillips and Rix (1993)
Blechnum indicum Burm.f. = *Blechnum serrulatum* Rich.	Blechnaceae	Bungwall Fern	Starchy rhizomes are eaten after roasting	Cribb and Cribb (1987) and Low (1989)
Blechnum orientale L.	Blechnaceae	Centipede Fern; Paku Lipan (Malay)	Starchy rhizomes are eaten after roasting	Cribb and Cribb (1987)
Boehmeria nivea (L.) Gaudich.	Urticaceae	China Grass, Ramie	China: root is eaten after boiling and peeling	Read (1946)
Boerhavia coccinea Mill.	Nyctaginaceae	Tar Vine, Hog Weed	Bland fibrous taproot is eaten	Cribb and Cribb (1987) and Harden (1990)
Boerhavia diffusa L.	Nyctaginaceae	Hog Weed, Horse Purslane; Zhu Er Yan, Huang Xi Xin (Chinese)	Fleshy portion of thick roots is roasted and eaten, sweetish and nutritious	Hu (2005)
Boerhavia spp.	Nyctaginaceae	Tar Vines	Bland fibrous taproot is eaten	Low (1991)
Boesenbergia pandurata (Roxb.) = *Boesenbergia rotunda* (L.) Mansfield	Zingiberaceae	See below	As for *Boesenbergia rotunda*	Facciola (1990)
Boesenbergia rotunda (L.) Mansfield	Zingiberaceae	Chinese Keys, Temu Kunci (Indonesia, Malaysia), Krachai (Thai)	Widely used as a spice in cooking traditional Malay, Indonesian, Laotian and Thai cuisine – mixed vegetable dishes, fish curries, soups and pickles. Aromatic rhizome is used in *ulam* (raw vegetable salad) in Malaysia and in salads in Thailand.	Ibrahim and Nugroho (1999), Saidin (2000), and van Wyk (2006)
Bolboschoenus caldwellii (V.J.) Soják	Cyperaceae	Sea Club-Rush	Grape-sized, sweet, fibrous tubers are eaten	Low (1989, 1991)
Bolboschoenus fluviatilis (Torr.) Soják	Cyperaceae	Marsh Club-Rush	As above	Low (1991)
Bolboschoenus maritimus (L.) Palla	Cyperaceae	Sea Club-Rush	Tubers are eaten after treatment	Cribb and Cribb (1987)
Bombax ceiba L.	Malvaceae	Sémul (India)	Succulent young roots are roasted and eaten after peeling off the skin cut into pieces, mixed with spices and eaten or boiled and eaten raw with salt	Gupta and Kanodia (1968a) and Shankarnarayan and Saxena (1987)
Bombax malabaricum DC. = *Bombax ceiba* L.	Malvaceae	Silk Cotton; Sawar, Savri, Shimla (Bombay)	As above	Darlington and Janaki Ammal (1945), Gammie (1902), and Gupta (1962)

Bongardia chrysogonum (L.) Spach	Berberidaceae	Ladies Nightcap	Roots are eaten boiled or roasted as food in Iran	Hedrick (1972) and Facciola (1990)
Boscia albitrunca (Burch.) Gilg & Benedict	Capparaceae	Shepherd's Tree, Witgat (Afrikaans)	Roots are source of meal and syrup in southern Africa	Uphof (1968), Fox et al. (1982), and Facciola (1990)
Bowenia spectabilis Hook.	Zamiaceae	Zamia Fern	Roots are eaten by aborigines	Cribb and Cribb (1987)
Brachychiton australis (Schott & Endl.) A. Terracc.	Malvaceae	Broad Leaf Bottle Tree	As above	Cribb and Cribb (1987)
Brachychiton populneus (Schott & Endl.) R. Br	Malvaceae	Black Kurrajong, Bottletree, Kurrajong, Kurrajong Bottle Tree	As above	Cribb and Cribb (1987)
Brachychiton diversifolius R. Br.	Malvaceae	Northern Kurrajong, Kurrajong		Facciola (1990)
Brachychiton rupestris (T. Mitch. ex Lindl.) K. Schum.	Malvaceae	Queensland Bottle Tree	Young roots are cooked as food by the aborigines	Cribb and Cribb (1987)
Brachystelma bingeri Chev. = *Raphionacme bingeri* (A. Chev.) J.-P. Lebrun & Stork	Apocynaceae	NF	In West Africa (Niger River region), tubers are eaten, after removal of resinous outer layer. It comprises largely of carbohydrate	Irvine (1952) and Uphof (1968)
Brasenia schreberi J.F. Gmel.	Cabombaceae	Water-Shield	Root is edible	Facciola (1990)
Brassica juncea (L.) Czern.	Brassicaceae	Root Mustard	Inflated, fleshy cylindrical taproot	Facciola (1990) and Opena (1994)
Brassica juncea (L.) Czern. subsp. *napiformis* (Pailleux & Bois) Gladis	Brassicaceae	Tuberous Rooted Chinese Mustard	Root is edible	Codex (2014)
Brassica napobrassica Mill.	Brassicaceae	Rutabaga, Swedish Turnip, Swede	Enlarged swollen root is eaten boiled, steamed, baked, fried, mashed, etc.	Phillips and Rix (1993), Hu (2005), and Santich et al. (2008)
Brassica napus cv. Group Rutabaga	Brassicaceae	As above	As above	Van den Bergh (1994)
Brassica napus L. var. *napobrassica* (L.) Reichenbach	Brassicaceae	As above	As above	Codex (2014)
Brassica napus Napobrassica Group	Brassicaceae	As above	As above	Facciola (1990)
Brassica oleracea var. *gongylodes* L. = *Brassica oleracea* L.	Brassicaceae	Kohlrabi, Cabbage Turnip	Young kohlrabi is used raw in salad; mature ones are peeled, cooked in soups and braised, can also be roasted, can be grated or cut into sticks for dips	Phillips and Rix (1993), Jansen et al. (1994), van Wyk (2006), and Santich et al. (2008)
Brassica rapa cv. Group Vegetable Turnip	Brassicaceae	Turnip	Roots are edible	Phillips and Rix (1993) and Toxopeus (1994)

(continued)

Table 1 (continued)

Brassica rapa L. var. *rapa* = *Brassica rapa* subsp. *rapa*	Brassicaceae	Garden Turnip	Root is edible, eaten raw, grated, glazed, sautéed in butter or cooked in cream, used in soups and stews	Phillips and Rix (1993), van Wyk (2006), and Codex (2014)
Brassica rapa Perviridis Group	Brassicaceae	Mustrad Spinach, Komatsuna	Thick tuberous roots of some cultivars are pickled and eaten	Tanaka (1976), Larkcom (1984), and Facciola (1990)
Brassica rapa Rapifera Group	Brassicaceae	Turnip, Fodder Turnip, Neeps	Roots are eaten raw, pickled, pureed, braised or used in stews, casseroles, soups, etc.	Facciola (1990) and van Wyk (2006)
Brodiaea capitata Benth. = *Dichelostemma capitatum* (Benth.) Alph. Wood	Asparagaceae	California Hyacinth, Grassnut, Wild Onion	Bulbs are eaten raw or boiled	Saunders (1920)
Brodiaea douglasii S. Watson = *Triteleia grandiflora* Lindl.	Asparagaceae	Clusterlily, Brodiaea, Grassnut, Fire-Cracker Flower, Blue Dicks	Corms are edible raw, fried, boiled and roasted	Facciola (1990)
Brodiaea grandiflora Smith = *Brodiaea coronaria* subsp. *coronaria*	Asparagaceae	Largeflower Tripletlily, Wild Hyacinth	Bulbs are best cooked as by slow roasting in hot ashes which develops the sweetness	Saunders (1920)
Brodiaea pulchella (Salisb.) Greene = *Dichelostemma congestum* (Sm.) Kunth	Asparagaceae	Wild Hyacinth, Common Saita, Common Brodiaea, Blue Dicks	Bulbs are eaten raw or boiled	Facciola (1990)
Bromelia caratas Hill = *Bromelia karatas* L.	Bromeliaceae	Camburito, Chigüichigüe, Curibijil, Quiribijil, Curujujul (Spanish)	In Brazil (northeast), bulbs are cooked and then sun-dried. Bulb is then pulverised and reduced to a flour	De Castro (1952)
Bromelia laciniosa Mart. ex Schult.f.	Bromeliaceae	Macambira (Spanish)	As above	De Castro (1952)
Bruguiera cylindrica (L.) Blume	Rhizophoraceae	White Burma Mangrove, Reflexed Orange Mangrove	Young radicals are eaten	Burkill (1966)
Brunoniella acaulis (R. Br.) Bremek.	Acanthaceae	Blue Yam	Roots are eaten	Cribb and Cribb (1987)
Brunoniella australis (Cav.) Bremek.	Acanthaceae	Blue Trumpet	Root is eaten after some preparation	Harden (1992)
Bryonia alba L.	Cucurbitaceae	Wild Bryony, Wild Hop, English Mandrake	France: starch of root is recommended as a famine food for extending bread flour after removing acrid element	Parmentier (1781) (cited by Freedman 2009)
Bulbine bulbosa (R. Br.) Haw.	Xanthorrhoeaceae	Bulbine Lily, Golden Lily	Bland starchy bulb is eaten by aborigines	Cribb and Cribb (1987), Low (1989, 1991), and Harden (1993)

Bunium alpinum Waldst. & Kit.	Apiaceae	NF	Tunisia: as for *Bunium chaberti*	Bouquet (1939)
Bunium bulbocastanum L.	Apiaceae	Earth Chestnut	In France, root is recommended as a famine food eaten raw or roasted	Facciola (1990) and Parmentier (1781) (cited by Freedman 2009)
Bunium chaberti (Batt.) Batt.	Apiaceae	NF	In Tunisia, tuberous roots are roasted being eaten. It is also boiled in salt water and seasoned with oil and spices	Bouquet (1939)
Bunium incrassatum (Boiss.) Amo = *Bunium pachypodium* P.W. Ball	Apiaceae	Alrhouda, Belbous, Aktsir, Ouetsir, Akser, Akoutsar (Arabic)	Tunisia: as for *Bunium chaberti*	Bouquet (1939)
Bunium macuca Boiss. = *Bunium alpinum* subsp. *atlanticum* Maire,	Apiaceae	NF	Tunisia: as for *Bunium chaberti*	Bouquet (1939)
Bunium persicum (Boiss.) B. Fedtsch.	Apiaceae	Cumin Black Root, Caraway Black Root	Tuberous roots are edible	Codex (2014)
Bupleurum falcatum L.	Apiaceae	Chai Hu, Hare's Ear Root	Himalayas (area unspecified): roots are eaten	Read (1946)
Burchardia umbellata R. Br.	Colchicaceae	Milkmaids	Crisp starchy tubers	Low (1989, 1991)
Butea frondosa Roxb. = *Butea monosperma* (Lam.) Taub.	Fabaceae	Dangs (Bombay)	In India, roots are toasted and eaten	Gammie (1902) and Watt (1908)
Butea monosperma (Lam.) Taub.	Fabaceae	Dhak, Pala (Rajasthan, Western India)	Succulent young roots are roasted or boiled and eaten with salt	Gupta and Kanodia (1968a) and Shankarnarayan and Saxena (1987)
Butomus umbellatus L.	Butomaceae	Flowering Rush	In China, steamed roots are eaten. Root may also be sun- dried, after which root is baked or made into a flour and steamed. In the Soviet Union (unspecified areas), root is reported to be eaten	Read (1946) and Uphof (1968)
Caesia alpina Hook.f.	Xanthorrhoeaceae	Alpine Grass Lily	Roots are eaten by aborigines	Harden (1993)
Caesia calliantha R.J.F. Hend.	Xanthorrhoeaceae	Pale Grass Lily	Roots are eaten by aborigines	Low (1991) and Harden (1993)
Caesia parviflora R. Br.	Xanthorrhoeaceae	Pale Grass Lily	Roots are eaten by aborigines	Low (1991) and Harden (1993)
Caesia setifera Baker	Xanthorrhoeaceae	Hairy Grass Lily	Roots are eaten by aborigines	Cribb and Cribb (1987) and Low (1989)
Caesia vittata R. Br. = *Caesia parviflora* var. *vittata* (R. Br.) R.J.F. Hend.	Xanthorrhoeaceae	Pale Grass Lily	Roots are eaten by aborigines	Low (1989) and Harden (1993)
Cakile edentula (Bigel.) Hook.	Brassicaceae	Sea Rocket	Canada: root is pounded and mixed with flour by native people in time of scarcity	Yanovsky (1936) and Hedrick (1972)

(continued)

Table 1 (continued)

Cakile maritima Scop.	Brassicaceae	European Sea Rocket	Roots are edible	Facciola (1990)
Caladenia filamentosa R. Br.	Orchidaceae	Daddy Long Legs, Spider Orchids	Tubers are watery sweetish	Harden (1993)
Caladenia gracilis R. Br.	Orchidaceae	Musky Caladenia, Musky Finger Orchid	Tubers are edible	Harden (1993)
Caladenia caerulea (R. Br.) Hopper & A.P. Br.	Orchidaceae	Blue Fairy Orchid, Blue Caladenia, Parson-in-the-Pulpit	Tubers are eaten by aborigines	Harden (1993)
Caladenia carnea R. Br.	Orchidaceae	Pink Fingers, Pink Finger Orchid	Tubers are edible	Low (1989, 1991) and Harden (1993)
Caladenia fuscata (Rchb.f.) M.A. Clem. & D.L. Jones	Orchidaceae	Dusky Fingers	Tubers are edible	Harden (1993)
Caladenia quadrifaria (R.S. Rogers) D.L. Jones	Orchidaceae	Large Pink Fingers Orchid	Tubers are edible	Harden (1993)
Caladenia spp.	Orchidaceae	Pink Fingers	Tubers are edible	Cribb and Cribb (1987)
Caladenia tentaculata Schltdl.	Orchidaceae	Green Comb Spider Orchid, Fringed Spider Orchid	Tubers are edible	Harden (1993)
Calamus rotang L.	Arecaceae	Rattan Palm; Pri (Assamese)	Rhizome is eaten in Karbi, Assam	Kar and Borthakur (2008)
Calathea allouia (Aublet) Lindl.	Marantaceae	Guinea Arrowroot, Leren, Sweet Corn Tuber	Root tubers are boiled and eaten like potato	Facciola (1990), Groen et al. (1996), and Codex (2014)
Caleana major R. Br.	Orchidaceae	Large Duck Orchid, Flying Duck Orchid	Tubers are edible	Harden (1993)
Caleana minor R. Br. = *Paracaleana minor* (R. Br.) Blaxell	Orchidaceae	Small Duck Orchid	As above	Harden (1993)
Calla palustris L.	Araceae	Marsh Calla, Water Arum, Water Dragon	In France, starch of root is recommended as a famine food for extending bread flour, after removal of acrid element. Rootstock can be dried and ground into an unpalatable but nutritious flour	Parmentier (1781) (cited by Freedman 2009) Facciola (1990) and Schofield (2003)
Callicarpa rubella Lindl.	Lamiaceae	Gopura Esing (Mishing), Bonmala (Assamese)	Bark and roots are chewed like betel nut; roots are eaten in Meghalaya	Patiri and Borah (2007) and Sawian et al. (2007)
Callicarpa vestita Wall. ex C.B. Clarke	Lamiaceae	Yarpo Esing (Mishing)	Bark and roots are chewed like betel nut	Patiri and Borah (2007)

Callirhoe involucrata (Torr. & A. Gray) A. Gray	Malvaceae	Purple Poppy Mallow	Sweet starchy roots are cooked and eaten	Hedrick (1972) and Facciola (1990)
Calochilus campestris R. Br.	Orchidaceae	Copper Beard Orchid	Tubers are eaten	Harden (1993)
Calochilus gracillimus Rupp	Orchidaceae	Slender Beard Orchid, Late Beard Orchid	As above	Harden (1993)
Calochilus robertsonii Benth.	Orchidaceae	Purple Beard Orchid	As above	Harden (1993)
Calochilus spp.	Orchidaceae	Bearded Orchid	Tubers are starchy bitter	Low (1991)
Calochortus nuttallii Torr.	Liliaceae	Sego Lily, Mariposa Lily, Sago Lily	Highly esteemed for its sweet corms. The cooking may be done by roasting in hot ashes or by steaming in pits. In North America, bulb is boiled and roasted and then made into flour by some native groups	Saunders (1920), Carr (1943), Uphof (1968), and Facciola (1990)
Calochortus venustus Douglas ex Benth.	Liliaceae	Mariposa Lily	As above	Saunders (1920)
Calochortus gunnisonii S. Watson	Liliaceae	Mariposa Lily, Gunnison's Mariposa Lily	As above	Saunders (1920)
Caltha leptosepala DC.	Ranunculaceae	Western Marsh Marigold, White Marsh Marigold	Boiled roots are eaten	Schofield (2003)
Caltha natans Pall.	Ranunculaceae	Floating Marsh Marigold	As above	Schofield (2003)
Caltha biflora DC. = *Caltha leptosepala* var. *howellii* Huth	Ranunculaceae	Alpine White Marsh Marigold, Two-Flowered Marsh Marigold	As above	Schofield (2003)
Caltha palustris L.	Ranunculaceae	Yellow Marsh Marigold	As above	Facciola (1990) and Schofield (2003)
Caltha palustris var. *barthei* Hance	Ranunculaceae	Kong Jing Lu Ti Cao (Chinese)	As above	Facciola (1990)
Calystegia japonica (Thunb.) Choisy = *Calystegia pubescens* Lindl.	Convolvulaceae	California Rose	In China, leafy shoots and roots are eaten. Roots are reported to be purgative	Read (1946)
Calystegia sepium (L.) R. Br.	Convolvulaceae	Large Bindweed, Hedge Bindweed	In China, root is washed and steamed or sun-dried and then broken into fragments, eaten with rice or ground into a meal and steamed in the form of cakes	Read (1946)
Camassia leichtlinii (Baker) S. Watson	Asparagaceae	Camas, Quamash, Indian Hyacinth, Camash, Wild Hyacinth	Bulbs are eaten raw, boiled, baked, fried, used in pies	Saunders (1920), Hedrick (1972), and Facciola (1990)

(continued)

Table 1 (continued)

Camassia esculenta (Nutt.) Lindl. = *Camassia quamash* (Pursh) Greene	Asparagaceae	Camas, Quamash	When boiled this little root is palatable and somewhat resembles the taste of the common potato	Saunders (1920)
Camassia quamash (Pursh) Greene	Asparagaceae	Camas, Small Camas, Common Camas	As for *C. leichtlinii*	Harrington (1974), Gibbons and Tucker (1979), and Facciola (1990)
Campanula pyramidalis L.	Campanulaceae	Chimney Bellflower	In France, cooked root is recommended as famine food	Parmentier (1781) (cited by Freedman 2009)
Campanula rapunculoides L.	Campanulaceae	Creeping Bellflower, Rampion Bellflower	Roots are eaten raw in salads or boiled and served with butter or cream sauce	Harrington (1974), Gibbons and Tucker (1979), and Facciola (1990)
Campanula rapunculus L.	Campanulaceae	Rampion Bellflower, Rampion, Rover Bellflower	Roots are eaten raw, boiled as vegetable or used in soups or stews	Facciola (1990), Santich et al. (2008), and Codex (2014)
Campanula urticaefolia All.	Campanulaceae	Bellflower	In France, cooked root is recommended as famine food	Parmentier (1781) (cited by Freedman 2009)
Canarina canariensis (L.) Vatke	Campanulaceae	Canary Island Bellflower	Roots are edible	Hedrick (1972), Kunkel (1984), and Facciola (1990)
Calandrinia eremaea Ewart	Portulacaceae	Small Purslane	Roots are eaten raw or cooked	Harden (1990)
Canna achiras Gill. = *Canna indica* L.	Cannaceae	Indian Shot, Canna	Rhizome is eaten, source of Indian arrowroot called *rous le mois* in Chile and Argentina	Hedrick (1972) and Facciola (1990)
Canna bidentata Bertol. = *Canna indica* L.	Cannaceae	Indian Shot, Balisier	In West Africa, starchy rhizome is eaten	Irvine (1952) and Uphof (1968)
Canna edulis Ker Gawl.	Cannaceae	Edible Canna, Queensland Arrowroot; Achira; Gruya, Par Baul Fauk, Nung Gum (Assamese)	Starch obtained from rhizome is used to make translucent noodles in Vietnam. Rhizome is eaten in Assam	Burkill (1966), Facciola (1990), Flores et al. (2003), Santich et al. (2008), Medhi and Borthakur (2012), and Codex (2014)
Canna indica L.	Cannaceae	Indian Shot	As above	Ong and Siemonsma (1996)
Canna lutea Mill. = *Canna indica* L.	Cannaceae	K ‘Uuwaap (Teenek)	In Yucatan, rhizome is eaten as a famine food by the Huastec Maya	Alcorn (1984)
Canna orientalis Rosc. = *Canna indica* L.	Cannaceae	Indian Shot	Rhizome is cooked and eaten as food	Burkill (1966)
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	Shepherd’s Purse	Plant with roots is a delicacy in northern and eastern China. Ground or chopped roots are used as ginger substitute	Facciola (1990), Schofield (2003), and Hu (2005)
Cardamine flexuosa With.	Brassicaceae	Wavy Bittercress	Roots are eaten	Facciola (1990)

Cardiocrinum giganteum (Wall.) Makino var. *yunnanense* (Leicht. ex Elwes) Stearn	Liliaceae	Yunnan Cardio Crinum; Bai He Qi (Chinese)	Rural people in mountains of central and western China extract starch from the bulbs	Hu (2005)
Carex spp.	Cyperaceae	Ware Sedge	Sweet, enlarged underground stem is eaten	Schofield (2003)
Carludovica palmata Ruiz & Pav.	Cyclanthaceae	Panama Hat Plant, Hat Palm	Rhizomes are used as salads and herb in Latin America	Kunkel (1984) and Facciola (1990)
Cartonema parviflorum Hassk.	Commelinaceae	Arda	Starchy tubers are eaten by aborigines	Cribb and Cribb (1987) and Low (1989, 1991)
Cartonema spicatum R. Br.	Commelinaceae	Arda	As above	Cribb and Cribb (1987) and Low (1989, 1991)
Carum carvi L.	Apiaceae	Caraway, Persian Cumin	Roots are edible, used in soups	Uphof (1968), Hedrick (1972), and Facciola (1990)
Carum gairdneri (Hook. & Arn.) A. Gray	Apiaceae	Yamp	Clustered, spindle-shaped tuberous root is eaten raw, has an agreeable, nutty taste, with a considerable sugar content	Saunders (1920)
Carum kelloggii A. Gray	Apiaceae	Wild Anise	Roots are eaten	Saunders (1920)
Cayratia clematidea (F. Muell.) Domin	Vitaceae	Native Grape	Root tubers are eaten after baking	Cribb and Cribb (1987)
Cayratia trifolia (L.) Domin	Vitaceae	Three Leaf Cayratia, Bush Grape, Native Grape	As above	Cribb and Cribb (1987)
Ceropegia bulbosa Roxb.	Apocynaceae	Dúdha Malida Kand, Malode (Bombay); Hedulo, Khapparkadu (western Rajasthan)	Tubers and leaves are eaten uncooked or boiled	Gammie (1902), Watt (1908), Gupta and Kanodia (1968a), Saxena (1979), and Facciola (1990)
Ceropegia cumingiana Decne.	Apocynaceae	Anareata	Fleshy rhizome is edible	Cribb and Cribb (1987) and Groen et al. (1996)
Ceropegia tuberosa Roxb. = *Ceropegia candelabrum* L.	Apocynaceae	Hadula (western Rajasthan)	Tubers are eaten raw or roasted	Shankarnarayan and Saxena (1987)
Chaerophyllum bulbosum L.	Apiaceae	Turnip-Rooted Chervil	Roots are eaten as vegetables	Facciola (1990) and Codex (2014)
Chaerophyllum bulbosum subsp. *prescottii* (DC.) Nyman	Apiaceae	Bulbous Chervil	As above	Facciola (1990)
Chamaescilla corymbosa (R. Br.) F. Muell. ex Benth.	Asparagaceae	Blue Star, Blue Squill	Tubers are pleasantly starchy	Low (1991)

(continued)

Table 1 (continued)

Chiloglottis diphylla R. Br.	Orchidaceae	Common Ant Orchid	Tubers are edible	Harden (1993)
Chiloglottis formicifera Fitzg.	Orchidaceae	Ant Orchid	As above	Harden (1993)
Chiloglottis palachila D.L. Jones & M.A. Clem.	Orchidaceae	Clubbed Ant Orchid	As above	Harden (1993)
Chiloglottis platyptera D.L. Jones	Orchidaceae	Barrington Tops Ant Orchid	As above	Harden (1993)
Chiloglottis pluricallata D.L. Jones	Orchidaceae	Brown Bird Orchid	As above	Harden (1993)
Chiloglottis sphyrnoides D.L. Jones	Orchidaceae	Ornate Ant Orchid	As above	Harden (1993)
Chiloglottis trapeziformis Fitzg.	Orchidaceae	Erect Ant Orchid	As above	Harden (1993)
Chiloglottis trilabra Fitzg. = *Chiloglottis reflexa* (Labill.) Druce	Orchidaceae	Long-Clubbed Wasp Orchid	As above	Harden (1993)
Chlorogalum pomeridianum (DC.) Kunth	Asparagaceae	Wavy-Leafed Soap Plant, California Soaproot	Roots are edible	Facciola (1990)
Chlorophytum tuberosum (Roxb.) Baker	Asparagaceae	Safed Mosali, Kolu Sevni (Bombay); Safed Musli (western Rajasthan)	India (Bombay Presidency): bulbs and leaves are eaten. Bulbs and leaves are dried and pounded into flour for bread	Gammie (1902)
Christella parasitica H. Lev.	Thelypteridaceae	Bihlongoni (Assamese)	Young frond and rhizomes are eaten cooked by Mishings and prepared as a special soup with chicken and given to the mother who has recently given birth and to the weak convalescents	Patiri and Borah (2007)
Chrysopogon zizanioides (L.) Roberty	Poaceae	Vetiver Grass, Khas Kahs, Khus Grass	Vetiver is used domestically in cooking; it is infused in tea and also used in baking	Balasankar et al. (2013)
Cibotium barometz (L.) J. Sm.	Cibotiaceae	Woolly Fern, Golden Chicken Fern, Golden Moss	Roots are eaten	Cui (1998), Dai et al. (2003), Cao et al. (2007), Yun et al. (2009a), and Liu et al. (2012)
Cichorium intybus L.	Asteraceae	Chicory	Roots are roasted and used as coffee substitute. Tubers are rich source of inulin and sugar	Facciola (1990), Hu (2005), Cabezas et al. (2002), and Codex (2014)
Cirsium arvense (L.) Scop.	Asteraceae	Creeping Thistle, Canada Thistle	Roots are eaten raw or cooked	Uphof (1968), Launert (1981), and Facciola (1990)
Cirsium oleraceum (L.) Scop.	Asteraceae	Cabbage Thistle, Meadow Cabbage	Swollen rootstock is edible	Uphof (1968), Hedrick (1972), and Facciola (1990)
Cirsium tanakae Matsum.	Asteraceae	Nohara Azami (Japanese)	Roots in pieces are steeped in water and preserved in miso	Tanaka (1976) and Facciola (1990)

Cirsium vulgare (Savi) Ten.	Asteraceae	Bull Thistle, Common Thistle, Spear Thistle	Roots are boiled and eaten as vegetable	Harrington (1974), Fernald et al. (1958), and Facciola (1990)
Cissus opaca F. Muell. = *Clematicissus opaca* (F. Muell.) Jackes & Rossetto	Vitaceae	Pepper Vine	Large tuber is eaten by aborigines	Cribb and Cribb (1987)
Claytonia acutifolia Pall. ex Schult.	Montiaceae	Bering Sea Spring Beauty	Fleshy taproot is used as potato substitute, raw, boiled, baked or stir-fried	Schofield (2003)
Claytonia caroliniana Michx.	Montiaceae	Broad-Leaved Spring Beauty, Carolina Spring Beauty	Roots are eaten raw or cooked like potatoes	Hedrick (1972), Uphof (1968), and Facciola (1990)
Claytonia megarhiza (A. Gray) Parry ex S. Watson	Montiaceae	Alpine Spring Beauty	Root is eaten raw or cooked, peeled than boiled or baked	Yanovsky (1936), Hedrick (1972), and Facciola (1990)
Claytonia tuberosa Pall. ex Schult.	Montiaceae	Tuberous Spring Beauty	Corm is used as potato substitute, raw, boiled, baked or stir-fried	Schofield (2003)
Claytonia virginica L.	Montiaceae	Spring Beauty	Small, deep-seated, round tuber of starchy composition and nutty flavour, which might serve at a pinch to stave off starvation and has indeed so served the aborigines	Saunders (1920) and Facciola (1990)
Clerodendrum fragrans (Vent.) R. Br. = *Clerodendrum chinense* (Osbeck) Mabb.	Lamiaceae	Fragrant Glorybower, Chou Mo Li, Chou Mu Dan (Chinese)	Roots are dried, cooked with pork to strengthen elderly people and to remove pain and stiffness of muscles and joints	Hu (2005)
Clerodendrum serratum (L.) Moon. = *Rotheca serrata* (L.) Steane & Mabb.	Lamiaceae	Phelang Riho (Assamese)	Roots are eaten in Karbi, Assam	Kar and Borthakur (2008)
Cnicus japonicus (Fish. ex DC.) Maxim. = *Cirsium japonicum* (Thunb.) Fish. ex DC.	Asteraceae	Cat Thistle	China: young leaves and roots are eaten	Read (1946)
Cochlospermum sp.	Bixaceae		Root is baked	Cribb and Cribb (1987)
Codonocarpus attenuatus (Hook.) H. Walter	Gyrostemonaceae	Bell Fruit Tree	Sappy roots are used as food	Harden (1990)
Codonocarpus cotinifolius (Desf.) F. Muell.	Gyrostemonaceae	Bell Fruit, Native Poplar	Sappy roots are used as food	Cribb and Cribb (1987)
Codonopsis pilosula (Franch.) Nannf.	Campanulaceae	Tang Shen, Dang Shen (Chinese)	Dried root slices are used in combination with astragalus root, goji berries, red dates, sliced Chinese yam with spare ribs for a tonifying soup	Hu (2005)

(continued)

Table 1 (continued)

Codonopsis javanica (Blume) Hook.f. & Thomson	Campanulaceae	Dang Shen (Chinese), Dang Sam (Vietnamese)	As above	Anonymous (2013)
Codonopsis lanceolata (Sieb. & Zucc.) Benth. & Hook.f.	Campanulaceae	Yang Ru (Chinese)	Root fresh or dried is cooked with pig feet for a dish for nursing mothers	Hu (2005) and Kim et al. (2006)
Codonopsis lancifolia (Roxb.) Moeliono = *Cyclocodon lancifolius* (Roxb.) Kurz	Campanulaceae	Gordang-Gordang (Indonesia), Mayom-Kaeo (Thai)	Starchy rhizome is cooked as food and vegetables during famine	Groen et al. (1996)
Codonopsis tangshen Oliver = *Codonopsis pilosula* subsp. *tangshen* (Oliver) D.Y. Hong	Campanulaceae	Sichuan Tangshen	As for dang shen	Hu (2005)
Colchicum commune Neck. = *Colchicum autumnale* L.	Colchicaceae	Autumn Crocus	In France, starch of root is recommended as a famine food for extending bread flour, after removal of bitter element	Parmentier (1781) (cited by Freedman 2009)
Coleus blumei Benth. = *Plectranthus scutellarioides* (L.) R. Br.	Lamiaceae	Coleus, Painted Nettle, Sayabana, Jacob's Coat	Tubers are eaten	Burkill (1966) and Facciola (1990)
Coleus dazo A. Chev. = *Plectranthus esculentus* N.E. Br.	Lamiaceae	Daju, Rizuka	Starchy root is peeled, boiled, served and eaten or pickled	Tanaka (1976) and Facciola (1990)
Coleus parviflorus Benth. = *Plectranthus rotundifolius* (Poir.) Spreng.	Lamiaceae	African Potato, Country Potato	Tubers are eaten like potatoes	Tanaka (1976), Ochse and van den Brink (1980), and Facciola (1990)
Coleus tuberosus (Blume) Benth. = *Plectranthus rotundifolius* (Poir.) Spreng.	Lamiaceae	African Potato, Country Potato	Tubers are usually eaten steamed or cooked with rice in Indonesia	Ochse and van den Brink (1980)
Colocasia affinis Schott	Araceae	Black Princess Taro, Black-Leaved Taro, Purple-Leaved Taro	Roots are eaten in Meghalaya	Sawian et al. (2007)
Colocasia esculenta (L.) Schott	Araceae	Taro, Kola, Kalo Kochu/Kolia Kochu (Assamese)	Tender leaves and corms and cormels are eaten as vegetable, specially with acidic fruit in various form in Assam. Roots are eaten in Meghalaya China: corms and cormels are boiled, cooked with meat or seafood, in soups or stews, and prepared for dessert. Hawaiian poi is made from cooked taro paste, also used as filling for Asian pastries cakes and buns and also in taro ice cream	Burkill (1966), Patiri and Borah (2007), Cribb and Cribb (1987), Facciola (1990), Sawian et al. (2007), Walter and Lebot (2007), Hu (2005), Brassicaceae Santich et al. (2008), Phillips and Rix (1993), Wilson and Siemonsma (1996), and Ochse and van den Brink (1980), codex

Colocasia esculenta (L.) var. *antiquorum* (Schott) Hubbard & Rehder	Araceae	Eddoes, Taro	As above	Codex (2014)
Colocasia esculenta (L.) var. *globifera* Engl. & Krause = *Colocasia esculenta* (L.) var. *antiquorum* (Schott) Hubbard & Rehder	Araceae	Eddoes, Taro	As above	Codex (2014)
Colocasia himalensis Royle = *Colocasia esculenta* (L.) Schott	Araceae	Dhakol (Kumaon region, western Himalayas)	Rhizomes are either boiled and cooked or roasted in ashes	Bhargava (1960) and Gupta (1962)
Colocasia nymphaeifolia (Vent.) Kunth = *Colocasia esculenta* (L.) Schott	Araceae	Karunai Kizhangu (Tamil), Kanda Gadda (Telugu)	Tubers are cooked and eaten	Shott (1887–1888) (cited by Freedman 2009)
Commiphora caerulea Burtt	Burseraceae	Wému (Sandawe)	In central Tanzania, young roots are chewed for juices	Newman (1975)
Commiphora neglecta Verd.	Burseraceae	Mu-Kerenju (Kikuyu)	In Kenya (Mbeere division, Embu district), leaves and roots are eaten. Root bark is peeled off; root is chewed like sugar cane	Riley and Brokensha (1988)
Conopodium majus (Gouan) Loret	Apiaceae	Pignut	Tubers are edible	Hedrick (1972), Facciola (1990), and Codex (2014)
Coniogramme emeiensis Ching & K.H. Shing	Pteridaceae	Golden Zebra, E Mei Feng Liao Jue (Chinese)	Rhizome starch is used for noodles	Dai et al. (2003) and Yun et al. (2009b)
Coniogramme intermedia Hieron.	Pteridaceae	Pu Tong Feng Liao Jue (Chinese)	As above	Dai et al. (2003) and Yun et al. (2009b)
Coniogramme intermedia var. *glabra* Ching	Pteridaceae	Wu Mao Feng Liao Jue (Chinese)	As above	Dai et al. (2003) and Yun et al. (2009b)
Coniogramme japonica (Thunb.) Diels	Pteridaceae	Feng Liao Jue (Chinese)	As above	Dai et al. (2003) and Yun et al. (2009b)
Coniogramme jinggangshanensis Ching & K.H. Shing	Pteridaceae	Jing Gang Shan Feng Liao Jue (Chinese)	As above	Dai et al. (2003) and Yun et al. (2009b)
Coniogramme robusta Christ (Christ)	Pteridaceae	Hei Zhou Feng Liao Jue (Chinese)	As above	Dai et al. (2003) and Yun et al. (2009b)
Coniogramme rosthornii Hieron.	Pteridaceae	Ru Tou Feng Liao Jue (Chinese)	As above	Dai et al. (2003) and Yun et al. (2009b)
Coniogramme simillima Ching ex K.H. Shing	Pteridaceae	NF	As above	Dai et al. (2003) and Yun et al. (2009b)

(continued)

Table 1 (continued)

Coniogramme taipaishanensis Ching & Y.T. Hsieh	Pteridaceae	Taibai Shan Feng Ya Jue (Chinese)	As above	Dai et al. (2003) and Yun et al. (2009b)
Conopholis americana (L.) Wallr.	Orobanchaceae	Squaw Root, Bear Corn, Indian Corn, American Cancer Root	Roots are edible cooked	Kaldy et al. (1980)
Consolida major Gilib.	Ranunculaceae	Larkspur	In France, root is recommended as a famine food. It may be cooked in the manner of *salisfy* or reduced to a pulp and blended into a confection as recommended for *Asphodelus albus*	Parmentier (1781) (cited by Freedman 2009)
Convolvulus chinensis Ker Gawl. = *Convolvulus arvensis* L.	*Convolvulaceae*	Chinese Bindweed; Fu-Fu-Miao, Tian Xuan Hua (Chinese)	Rhizomes are eaten in a gruel	Hu (2005)
Convolvulus erubescens Sims	*Convolvulaceae*	Australian Bindweed	Fibrous and not especially tasty roots	Low (1989, 1991)
Cordyline australis (G. Forst.) Endl.	Asparagaceae	Cabbage Tree, Ti Kouka	Roots are eaten or brewed into an intoxicating drink	Tanaka (1976) and Facciola (1990)
Cordyline fruticosa (L.) A. Chev.	Asparagaceae	Ti, Ti Plant, La'i, Good Luck Plant	Roasted root is fermented in water and distilled into an alcoholic beverage. Root is rich in sugars, and when baked, the confection is eaten or used to sweeten puddings and other foods	Hedrick (1972), Ochse and van den Brink (1980), and Facciola (1990)
Cordyline sp.	Asparagaceae	Palm Lily	Underground stem is eaten as emergency food	Cribb and Cribb (1987)
Cordyline terminalis (L.) Kunth = *Cordyline fruticosa* (L.) A. Chev.	Asparagaceae	As for *C. Fruticosa*	Tuber is cooked as famine food. Puree from grated tuber is mixed with coconut milk and used to prepare small *lap-laps* which after cooking are crushed in the hand and eaten in Oceania	Walter and Lebot (2007)
Corybas fimbriatus (R. Br.) Rchb.f.	Orchidaceae	Fringed Helmet-Orchid	Tubers are edible	Harden (1993)
Corybas hispidus D.L. Jones	Orchidaceae	Bristly Helmet-Orchid	Tubers are edible	Harden (1993)
Corybas montanus D.L. Jones	Orchidaceae	Mt Maroon Helmet-Orchid	Tubers are edible	Harden (1993)
Corybas species A	Orchidaceae	Sphagnum Helmet-Orchid	Tubers are edible	Harden (1993)
Costus speciosus (J. König) Sm. = *Cheilocostus speciosus* (J. König) C. Specht	Costaceae	Crepe Ginger, Malay Ginger, Wild Ginger	Tuberous rhizomes are used as food and spice	Facciola (1990), Groen et al. (1996), Hu (2005), and Codex (2014)
Crambe cordifolia Steven	Brassicaceae	Colewort	Roots are edible	Hedrick (1972) and Kunkel (1984)

Crambe orientalis L.	Brassicaceae	Oriental Sea Kale	Roots are used as horseradish substitute	Hedrick (1972) and Tanaka (1976)
Crambe tatarica Sebeok	Brassicaceae	Tartar Bread Plant	Root is eaten raw in salads or cooked as a vegetable. It can be dried, grounded into powder and mixed with cereal flours when making bread	Hedrick (1972) and Tanaka (1976)
Crinum defixum Ker Gawl. = *Crinum viviparum* (Lam.) R. Ansari & V.J. Nair.	Amaryllidaceae	River Crinum Lily	India: root is eaten	Watt (1908)
Crinum flaccidum Herb.	Amaryllidaceae	Darling Lily, Murray Lily, Macquarie Crinum, Inland Crinum	Bulb is used as a source of arrowroot	Cribb and Cribb (1987) and Harden (1993)
Crocus sativus L.	Iridaceae	Saffron, Asian Saffron, Persian	Root is eaten roasted	Facciola (1990) and Lim (2014)
Cryptostylis erecta R. Br.	Orchidaceae	Tartan Tongue-Orchid, Turban Orchid	Fleshy starchy tubers are eaten by aborigines	Harden (1993)
Cryptostylis hunteriana Nicholls	Orchidaceae	Leafless Tongue-Orchid	Fleshy starchy tubers are eaten by aborigines	Harden (1993)
Cryptostylis leptochila F. Muell. ex Benth.	Orchidaceae	Small Tongue-Orchid, Red Tongue-Orchid	Fleshy starchy tubers are eaten by aborigines	Harden (1993)
Cryptostylis sp.	Orchidaceae	Tongue Orchids	Fleshy starchy tubers are eaten by aborigines	Cribb and Cribb (1987)
Cryptostylis subulata (Labill.) Rchb.f.	Orchidaceae	Large Tongue-Orchid, Cowslip Orchid	Fleshy starchy tubers are eaten by aborigines	Harden (1993)
Cryptotaenia canadensis (L.) DC.	Apiaceae	Honewort, Wild Chervil	Root is boiled in salt water and served with butter and sprinkle of parsley or cream sauce	Fernald et al. (1958) and Facciola (1990)
Cryptotaenia japonica Hassk.	Apiaceae	Mitsuba, Japanese Parsley, Japanese Honewort	Blanched roots are sautéed with sesame oil or boiled together with parsnip	Tanaka (1976), Morton (1976), Larkcom (1984), and Facciola (1990)
Cucurbita foetidissima Kunth	Cucurbitaceae	Buffalo Gourd	Starch is obtained from roots	Hu (2005)
Curculigo ensifolia R. Br.	Hypoxidaceae	Grass Potato	Slender taproots are eaten by aborigines	Cribb and Cribb (1987) and Low (1989, 1991)
Curcuma aeruginosa Roxb.	Zingiberaceae	Pink And Blue Ginger, Dark Blue Temu	Rhizome is used as spice	Burkill (1966)

(continued)

Table 1 (continued)

Curcuma amada Roxb.	Zingiberaceae	Tharmit Tharve Am Haladhi, Am-Ada (Assamese)	Rhizome is eaten in Karbi, Assam. Rhizome is used to prepare salad or chutney or eaten raw. It is also used as medicinal for its zedoary content	Patiri and Borah (2007) and Kar and Borthakur (2008)
Curcuma angustifolia Roxb.	Zingiberaceae	Indian Arrowroot	Rhizome has edible starch	Ibrahim and Jansen (1996a)
Curcuma aromatica Salisb.	Zingiberaceae	Wild Turmeric, Yellow Zedoary	Rhizome is used as spice, source of starch	Ibrahim and Jansen (1996a) and Hu (2005)
Curcuma australasica Hook.f.	Zingiberaceae	Native Ginger	Tuberous roots are roasted and eaten by aborigines	Cribb and Cribb (1987)
Curcuma caulina J. Graham = *Hitchenia caulina* (J. Graham) Baker	Zingiberaceae	Chavar	In India (Deccan), tuberous root is eaten	Watt (1908)
Curcuma domestica Valeton = *Curcuma longa* L.	Zingiberaceae	Turmeric	Rhizome is used as spice	Phillips and Rix (1993) and Hu (2005)
Curcuma longa L.	Zingiberaceae	Turmeric, Kunyit, Temu Kunyit (Malaysia), Khamin (Thai)	Rhizome is used as culinary spice in Asian dishes, curries. Ground turmeric is used in food industry as colouring agent in processed sauces, curry pastes and sauces; turmeric oil and oleoresins are similarly used. Roots are eaten in Meghalaya	Burkill (1966), Morton (1976), Ochse and van den Brink (1980), Facciola (1990), Dahal and Idris (1999), Saidin (2000), Hu (2005), Sawian et al. (2007), and Walter and Lebot (2007)
Curcuma mangga Valeton & Zijp	Zingiberaceae	Mango Ginger; Temu Pauh, Temu Mangga (Malaysia); Khamin Khao (Thai)	Rhizome is used as spice	Burkill (1966), Morton (1976), Ochse and van den Brink (1980), Facciola (1990), Saidin (2000), and Van den Bergh (1994)
Curcuma phaeocaulis Valeton	Zingiberaceae	E Zhu (Chinese)	Rhizome is used as spice	Lu et al. (2013)
Curcuma pierreana Gagnep.	Zingiberaceae	NF	Rhizome is highly aromatic, source of starch	Ibrahim and Jansen (1996a)
Curcuma pseudomontana R. Grah.	Zingiberaceae	Hill Turmeric	In India (Deccan), rhizomes are eaten	Watt (1908)
Curcuma purpurascens Blume	Zingiberaceae	Temu Tis, Koneng Pinggang, Kunir Tinggang (Indonesia)	Rhizome is edible	Ochse and van den Brink (1980)
Curcuma zanthorrhiza Roxb.	Zingiberaceae	Temulawak (Malaysia)	Rhizome is used as spice or eaten raw	Burkill (1966), Ochse and van den Brink (1980), Facciola (1990), Jansen (1996a), and Saidin (2000)

Curcuma zedoaria (Christm.) Roscoe	Zingiberaceae	Zedoary, Temu Kuning (Malaysia)	Rhizome is used as spice; young rhizome is added to salads	Burkill (1966), Morton (1976), Ochse and van den Brink (1980), Facciola (1990), Ibrahim and Jansen (1996a, b), and Saidin (2000)
Cyclosorus interruptus (Willd.) H. Ito = *Thelypteris interrupta* (Willd.) K. Iwats.	Thelypteridaceae	Willdenow's Maiden Fern	Roots are edible roasted	Cribb and Cribb (1987)
Cymbidium canaliculatum R. Br.	Orchidaceae	Tiger Orchid, Channeled Cymbidium, Inland Tree Orchid	The pseudobulbs are rich in starch and while recorded as being used cooked or raw are mucilaginous and insipid. The 'arrowroot' may be removed by washing out the pounded starch and allowing it to settle. Tubers and stems are eaten	Maiden (1889) and Harden (1993)
Cynanchum bungei Decne.	Apocynaceae	Bai Shou Wu (Chinese)	Starch from fleshy roots is used with sugar as health food	Hu (2005)
Cynanchum caudatum (Miq.) Maxim.	Apocynaceae	NF	China: leaves and roots are eaten. The root is peeled, sliced, boiled in several changes of water to remove the acrid element, washed and boiled again until it is very thoroughly cooked	Read (1946), Tanaka (1976), and Kunkel (1984)
Cynanchum forrestii Schlechter	Apocynaceae	Da Li Bai Qian (Chinese)	Rootstock and wiry roots are dried, used in soup and tasty beverage in Yunnan	Hu (2005)
Cynanchum otophyllum C.K. Schneid.	Apocynaceae	Qing Yang Shen (Chinese)	Roots are boiled with pork or spare ribs in a special dish	Hu (2005)
Cynanchum wilfordii (Maxim.) Hemsl.	Apocynaceae	Ge Shan Xiao (Chinese)	Roots are used to extract starch	Hu (2005)
Cynara cardunculus L.	Asteraceae	Cardoon	Roots are cooked like carrot or parsnip	Hedrick (1972), Halpin (1978), and Facciola (1990)
Cyperus bifax C.B. Clarke = *Cyperus rotundus* L.	Cyperaceae	Downs Nutgrass	Tubers produced on rhizomes are dried, coat removed, shaken with hot ashes, eaten raw or rubbed to a powder and eaten as porridge	Cribb and Cribb (1987) and Harden (1993)

(continued)

Table 1 (continued)

Cyperus bulbosus Vahl	Cyperaceae	Nalgoo (Australia)	Tubers are pleasantly starchy. In India (Bombay Presidency), bulbs are dried and pulverised and then mixed with *jowar*, *bajrai* (millet) or wheat flour to make bread	Gammie (1902), Paton and Dunlop (1904), Irvine (1957), Burkill (1966), Gupta and Kanodia (1968a), Saxena (1979), Low (1991), and Jansen and Aguilar (1996)
Cyperus esculentus L.	Cyperaceae	Chufa, Tiger Nut, Yellow Nutgras	Chufa's hard tubers are sweet and tasty. In Zimbabwe, tubers are eaten raw or cooked	Saunders (1920), Burkill (1966), Cribb and Cribb (1987), Zinyama et al. (1990), Jansen and Aguilar (1996), and Codex (2014)
Cyperus esculentus L. var. *sativus* Boeckeler = *Cyperus esculentus* L.	Cyperaceae	Yellow Nut Grass, Chufa; You Sha Cao (Chinese)	Tubers are eaten in China	Hu (2005)
Cyperus jeminicus Rottb.	Cyperaceae	NF	In India, tubers are ground into flour	Watt (1908)
Cyperus papyrus L.	Cyperaceae	Egyptian Reed, Paper Reed	Starchy rhizomes and culms are edible	Mahr (2011)
Cyperus rotundus L.	Cyperaceae	Nutgrass, Purple Nutgrass; Mothee, Motha (Rajasthan)	In France, root is recommended as famine food, can be eaten raw or cooked, can be dried and reduced to a flour. In India (Jaisalmer district, Rajasthan), fibre and cuticle of root are removed; root is dried, ground and made into bread and sometimes mixed with other flours; in western Rajasthan, tubers are roasted, also boiled, outer skin peeled off, and the starchy rhizome eaten with spices	Parmentier (1781) (cited by Freedman (2009), Saunders (1920), Burkill (1966), Saxena (1979), Cribb and Cribb (1987), Harden (1993), and Jansen and Aguilar (1996)
Cyrtosperma chamissonis Schott = *Cyrtosperma merkusii* (Hassk.) Schott	Araceae	Giant Swamp Taro, Swamp Taro	Corm is sliced, boiled or cooked or baked	Burkill (1966), Facciola (1990), Phillips and Rix (1993), and Walter and Lebot (2007)
Cyrtosperma edule Schott = *Cyrtosperma merkusii* (Hassk.) Schott	Araceae	Giant Swamp Taro, Swamp Taro	As above	Burkill (1966)
Cyrtosperma merkusii (Hassk.) Schott	Araceae	Giant Swamp Taro, Swamp Taro	As above	Evangelio (1996)
Cyrtostylis reniformis R. Br.	Orchidaceae	Gnat Orchid	Tubers can be eaten	Harden (1993)
Dalea candida (Michx.) Willd.	Fabaceae	White Prairie Clover	Root is eaten raw or chewed, eaten as delicacy by children	Yanovsky (1936), Tanaka (1976), and Facciola (1990)

Dalea gattingeri (A. Heller) Barneby	Fabaceae	Purple Tassels	Root is eaten raw or chewed	Yanovsky (1936), Uphof (1968), and Tanaka (1976)
Dalea purpurea Vent	Fabaceae	Purple Prairie Clover	Root is eaten raw or chewed	Facciola (1990)
Dahlia pinnata Cav.	Asteraceae	Garden Dahlia	Sweet tuber extract is used as a beverage or flavouring. It is mixed with hot or cold water or milk or sprinkled on ice cream	Uphof (1968), Hedrick (1972), Facciola (1990), and Lim (2014)
Daucus carota L.	Apiaceae	Carrot, Queen Anne's Lace	Carrot can be eaten raw; as a solo dish it can be served steamed, boiled, with dill, honey and butter or baked or roasted; they can be sautéed, used in soups, stocks, stews, braised dishes. They can be used as accompanying vegetable in many dishes. Carrot can be grated and used in carrot cakes	Facciola (1990), Phillips and Rix (1993), van der vossen and Sambas (1994), Walter and Lebot (2007), Santich et al. (2008), and Codex (2014)
Daucus carota Sativus Group	Apiaceae	As above	As above	Facciola (1990)
Daucus pusillus Michx.	Apiaceae	American Carrot, Rattlesnake Weed	Navajo Indians eat the root raw or cooked	Yanovsky (1936) and Facciola (1990)
Daucus vulgaris Neck. = *Daucus carota* L.	Apiaceae	Wild Carrot	France: root is recommended as a famine food	Parmentier (1781) (cited by Freedman 2009)
Dentaria diphylla Michx. = *Cardamine diphylla* (Michx.) Alph. Wood.	Brassicaceae	Two-Leaved Toothwort, Pepper-Root, Crinkleroot	Crisp white rootstock is eaten as popular nibble, having flavour of horseradish; it is also added to green salads and sandwiches with salt or grated and prepared like horseradish	Fernald et al. (1958), Gibbons and Tucker (1979), and Facciola (1990)
Dentaria laciniata Muhl. ex Willd. = *Cardamine concatenata* (Michx.) O. Schwarz.	Brassicaceae	Cut-Leaved Toothwort	Crisped, peppery root is chopped and added to salads or use for preparation of spices and sauces. It goes well with sandwiches with luncheon meat	Gibbons and Tucker (1979) and Facciola (1990)
Dichelostemma pulchellum var. *pauciflorum* (Torr.) Hoover = *Dichelostemma capitatum* subsp. *pauciflorum* (Torr.) Keator	Asparagaceae	Blue Dick	North America (Arizona): tuber is eaten by Native American Papago group	Castetter and Bell (1942)
Dichopogon fimbriatus (R. Br.) J.F. Macbr.	Asparagaceae	Nodding Chocolate Lily	Translucent, bitter, tuberous roots are used as food	Low (1989, 1991) and Harden (1993)
Dichopogon strictus	Asparagaceae	Chocolate Lily	Translucent, bitter, tuberous roots are used as food	Low (1989, 1991)

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Table 1 (continued)

Dioscorea aculeata Balb. ex Kunth = *Dioscorea cayennensis* Lam.	Dioscoreaceae	Fancy Yam, Potato Yam, Lesser Yam, Lesser Asiatic Yam, Igname; Man-Alu (Kumaon region, western Himalayas)	Roots are cut and boiled prior to eating	Bhargava (1960) and Ochse and van den Brink (1980)
Dioscorea alata L.	Dioscoreaceae	Purple Yam, Greater Yam, Winged Yam, Water Yam, White Yam; Kath Alu (Assamese); Yams Kalung (Tamil); Niluva Pendalum (Telugu)	Tubers are eaten cooked as vegetable. In China, tubers are used in soups. In Oceania, tuber is cut into pieces and baked or roasted whole or boiled in marmite or grated and used for *lap-lap*	Burkill (1966), Ochse and van den Brink (1980), Low (1991), Onwueme and Ganga (1996), Onwueme (1996a), Hu (2005), Patiri and Borah (2007), Walter and Lebot (2007), and Codex (2014)
Dioscorea anguina Roxb. = *Dioscorea pubera* Blume	Dioscoreaceae	Kakalu (Bengali), Savida Dumpa (Telugu)	Tuber is eaten in India	Watt (1908)
Dioscorea belophylla (Prain) Voigt ex Haines	Dioscoreaceae	Spear-Leaved Yam	In India (Garhwal Himalayas), tuber is eaten after repeated boiling, washing and baking	Gupta (1962)
Dioscorea bulbifera L.	Dioscoreaceae	Aerial Yam, Air Potato, Air Yam, Bitter Yam, Cheeky Yam, Potato Yam, Wild Yam; Gosh Alu (Assamese); Ho (Hawaiian); Genthi (Kumaon region, western Himalayas); Kapuang (Thai Sakai)	Root tubers are eaten cooked as vegetable during winter in India (Kumaon region, western Himalayas): axillary tubers are cut into pieces, steeped in water and boiled prior to eating. Hawaii: aerial bulbils are eaten. Yams are baked and boiled, or fried slices of tuber or pureed tuber may be added to soups, stew, soufflés, fritter and various sweet dishes	Patiri and Borah (2007), Cribb and Cribb (1987), Wightman and Andrews (1989), Low (1989), Facciola (1990), Bhargava (1960), Handy (1940), Neal (1965), Sturtevant, Burkill (1966), Hu (2005), Onwueme (1996a), and Walter and Lebot (2007)
Dioscorea calcicola Prain & Burkill	Dioscoreaceae	Bayae (Thai Sakai)	Tuber is the main source of carbohydrate for the Sakai tribe in peninsular Thailand	Maneenoon et al. (2008)
Dioscorea cayenensis Lam.	Dioscoreaceae	Yellow Guinea Yam, Yellow Yam, White Yan	Yams are used to make fufu, may also be used in the same way as potatoes or sweet potatoes	Burkill (1966), Facciola (1990), van Wyk (2006), and Codex (2014)
Dioscorea cumingii Prain & Burkill	Dioscoreaceae	Lima-Lima (Tagalog), Kasi (Igorot), Pari (Bagobo)	Tuber is used as food in Luzon (Philippines)	Groen et al. (1996)
Dioscorea daunea Prain & Burkill	Dioscoreaceae	Suna (Thai Sakai)	Tuber is used as substitute for *Dioscorea* food species during famine	Maneenoon et al. (2008)

Dioscorea deltoidea Wall. ex Griseb.	Dioscoreaceae	Nepal Yam; Gun (Kumaon region, western Himalayas)	Tubers are cut into pieces, steeped in water and boiled and/or baked prior to eating	Bhargava (1960) and Gupta (1962)
Dioscorea divaricata Blanco	Dioscoreaceae	Pakit, Kiroi (Tagalog), Sulian (Iloko), Baklaiakang (Bisaya)	Tuber is used as food in the Philippines, baked, boiled or fried	Groen et al. (1996)
Dioscorea dumetorum Kunth (Pax)	Dioscoreaceae	Cluster Yam; Ma-Nyeny, E-Dyeny (Bedik, Gold Coast); Rogon Biri (Hausa Nigeria)	In Gold Coast, tuber is used as a famine food. The tuber is boiled, peeled, sliced, pounded and steeped in running (preferably salt) water	Irvine (1952), Burkill (1966), Ferry et al (1974), and Mortimore (1989)
Dioscorea esculenta (Lour.) Burkill	Dioscoreaceae	Lesser Asiatic Yam, Sweet Yam, Potato Yam; Ruipheng Selu (Assamese)	Tuber is eaten in Karbi, Assam Yams are baked and boiled, or fried slices of tuber or pureed tuber may be added to soups, stew, soufflés, fritter and various sweet dishes	Burkill (1966), Ochse and van den Brink (1980), Facciola (1990), Onwueme (1996a, b), Hu (2005), van Wyk (2006), Walter and Lebot (2007), Kar and Borthakur (2008), and Codex (2014)
Dioscorea esculenta (Lour.) Burkill var. *fasciculata* (Roxb.) Prain & Burkill = *Dioscorea esculenta* (Lour.) Burkill	Dioscoreaceae	Moa Alu (Assamese)	Tubers are used as vegetable	Patiri and Borah (2007)
Dioscorea filiformis Blume	Dioscoreaceae	Wauh (Malaysia), Aroi Huwi Curuk (Sumatra), Dudung (Java), Balun (Thai Sakai)	Tubers are boiled and eaten in Malaysia. Tuber is the main source of carbohydrate for the Sakai tribe in peninsular Thailand	Groen et al. (1996) and Maneenoon et al. (2008)
Dioscorea gibbiflora Hook.f. = *Dioscorea filiformis* Blume	Dioscoreaceae	Wild Yam	Tuber is eaten	Burkill (1966)
Dioscorea glabra Roxb.	Dioscoreaceae	Mandong (Thai), Luntak (Thai Sakai)	Tubers (glutinous and starchy) are used as food in peninsular Malaysia and Andaman islands. Tuber is the main source of carbohydrate for the Sakai tribe in peninsular Thailand	Groen et al. (1996) and Maneenoon et al. (2008)
Dioscorea hastifolia Nees	Dioscoreaceae	Warrine	Tuber is eaten	Low (1989)
Dioscorea hemsleyi Prain & Burkill	Dioscoreaceae	Glutinous; Nian Shan Yao (Chinese)	Tuber is eaten	Hu (2005)
Dioscorea hirtiflora Benth.	Dioscoreaceae	Mng'oko (Tanzania)	Sierra Leone, Nigeria (northern): eaten as a famine food	Irvine (1952)

(continued)

Table 1 (continued)

Dioscorea hispida Dennst.	Dioscoreaceae	Intoxicating Yam, Asiatic Bitter Yam; Gadog, Gadong, Gadong Lilin, Gadong Mabuk, Gadung (Malay)	Tuber is eaten	Burkill (1966), Onwueme (1996c), Ochse and van den Brink (1980), and Codex (2014)
Dioscorea japonica Thunb.	Dioscoreaceae	Glutinous Yam, Chinese Yam, Japanese Yam, Taiwanese Yam, Yama-No-Imo	Tuber is eaten in China	Read; Facciola (1990), Burkill (1966), Hu (2005), and Codex (2014)
Dioscorea laurifolia Wall. ex Hook.f.	Dioscoreaceae	Clangporn (Thai Sakai)	Tubers are eaten in peninsular Malaysia	Burkill (1966) and Groen et al. (1996)
Dioscorea luzonensis Schauer	Dioscoreaceae	Pakit, Mayabang (Tagalog) Kamangeg (Iloko)	Tubers are used for food	Groen et al. (1996)
Dioscorea macrostachya Benth. = *Dioscorea mexicana* Scheidw.	Dioscoreaceae	Panil Book	Tuber is cooked and eaten in Mexico	Alcorn (1984), Kunkel (1984), and Facciola (1990)
Dioscorea macroura Harms = *Dioscorea sansibarensis* Pax	Dioscoreaceae	Zanzibar Yam	Tropical Africa: eaten as a famine food	Irvine (1952) and Uphof (1968)
Dioscorea membranacea	Dioscoreaceae	Chatong (Thai Sakai)	Tuber is used as substitute for *Dioscorea* food species during famine	Maneenoon et al. (2008)
Dioscorea minutiflora Engl.	Dioscoreaceae	Aha Bayere (Twi, Gold Coast); Magoraza, Hazara (Hausa, Nigeria)	Gold Coast: eaten as a famine food. Nigeria (Kano State, northern): tuber is eaten	Irvine (1952) and Mortimore (1989)
Dioscorea nummularia Lam.	Dioscoreaceae	Prickly Yam	Tubers are eaten	Low (1991), Onwueme (1996a), and Walter and Lebot (2007)
Dioscorea opposita Thunb = *Dioscorea oppositifolia* L.	Dioscoreaceae	Chinese Yam, Korean Yam, Japanese Mountain Yam, Nagaimo, Yamaimo	Tuber is eaten	Burkill (1966), Facciola (1990), Hu (2005), van Wyk (2006), and Codex (2014)
Dioscorea oppositifolia L.	Dioscoreaceae	As above	India (Deccan): tuber is eaten	Watt (1908) and Facciola (1990)
Dioscorea orbiculata Hook.f.	Dioscoreaceae	Ubi Garam (Indonesia); Takob, Ubi Garam (Malaysia); Man Tayong (Thai); Takob (Thai Sakai)	Tubers are eaten in peninsular Malaysia. Tuber is the main source of carbohydrate for the Sakai tribe in peninsular Thailand	Burkill (1966), Groen et al. (1996), and Maneenoon et al. (2008)
Dioscorea owenii Prain & Burkill	Dioscoreaceae	NF	Tubers are eaten	Burkill (1966)

Dioscorea pentaphylla L.	Dioscoreaceae	Fiveleaf Yam; Pi'A (Hawaiian); Ser (Thai Sakai); Pachpotia Alu, Ruipheng (Assamese); Chai, Chavi, Alshi, Shahada, Kala Kand, Jaglia Che Kand, Kadu Kand (Bombay Presidency); Taigun, Takuli (Kumaon region, western Himalayas); Kanta-Alu (western Rajasthan)	In India, tubers are cut into pieces, steeped in water and boiled or baked prior to eating. In Hawaii, tuber is steamed and eaten warm. In Oceania, tubers are boiled baked or used in *lap-lap*. In peninsular Thailand, tubers are the main source of carbohydrate for the Sakai	Gammie (1902), Watt (1908), Handy (1940), Bhargava (1960), Gupta (1962), Gupta and Neal (1965), Burkill (1966), Gupta and Kanodia (1968a), Low (1989), Onwueme (1996a), Patiri and Borah (2007), Walter and Lebot (2007), Ochse and van den Brink (1980), Maneenoon et al. (2008), and Kar and Borthakur (2008)
Dioscorea persimilis Prain & Burkill = *Dioscorea hamiltonii* Hook.f.	Dioscoreaceae	Khoai Mai, Ciu Mai (Vietnamese)	Tuber is eaten, boiled in soups	Tanaka and Nguyen (2007)
Dioscorea piscatorum Prain & Burkill	Dioscoreaceae	Fish Poison Yam, Tuba Gunjo (Indonesia), Tuba Ubi (Malaysia), Kiyak (Thai Sakai)	Tubers are eaten boiled, baked or roasted. Tuber is used as substitute for *Dioscorea* food species during famine in peninsular Thailand	Burkill (1966), Groen et al. (1996), and Maneenoon et al. (2008)
Dioscorea polyclados Hook.f.	Dioscoreaceae	Kedut (Sumatra), Kedut (Malaysia)	Tubers are eaten after several boilings or baked in peninsular Malaysia	Burkill (1966) and Groen et al. (1996)
Dioscorea polystachya Turcz.	Dioscoreaceae	Chinese Yam	Tubers are eaten	Codex (2014)
Dioscorea prainiana R. Kunth	Dioscoreaceae	Ubi Kelonak, Kelunoh, Kelana (Malaysia)	Tubers are eaten in peninsular Malaysia	Burkill (1966)
Dioscorea prazeri Prain & Burkill	Dioscoreaceae	Sehod (Thai Sakai)	Tubers are used as substitute for *Dioscorea* food species during famine in peninsular Thailand	Maneenoon et al. (2008)
Dioscorea preussii Pax	Dioscoreaceae	Preuss' Dioscorea	In tropical, central Africa, tuber is eaten in times of famine	Irvine (1952)
Dioscorea pubera Blume	Dioscoreaceae	Rui-Chilong	Bulbs and tubers are eaten in Karbi, Assam	Groen et al. (1996) and Kar and Borthakur (2008)
Dioscorea pyrifolia Kunth	Dioscoreaceae	Ubi Babi, Badak, Akar Kemnyan Paya, Huwi Upas (Sundanese), Ilus (Javanese), Hngo (Thai Sakai)	Tubers are eaten after several boilings or baked in peninsular Malaysia. Tuber is the main source of carbohydrate for the Sakai tribe in peninsular Thailand	Burkill (1966), Groen et al. (1996), and Maneenoon et al. (2008)
Dioscorea quinata Walter = *Dioscorea villosa* L.	Dioscoreaceae	Magiya, Munia (Kumaon region, western Himalayas, India)	Tubers are cut into pieces, steeped in water and boiled, prior to eating	Bhargava (1960)

(continued)

Table 1 (continued)

Dioscorea rotundata Poir. = *Dioscorea cayennensis* subsp. *rotundata* (Poir.) J. Miege	Dioscoreaceae	Eight-Month Yam, Round White Yam, White Yam, White Guinea Yam	Yams are used to make fufu, may also be used in the same way as potatoes or sweet potatoes	Akinwande et al. (2007) and Codex (2014)
Dioscorea sagitatta Poir.	Dioscoreaceae	Fiveleaf Yam, Tarur (Kumaon region, western Himalayas, India)	Axillary tubers are cut into pieces, steeped in water and boiled prior to eating	Bhargava (1960)
Dioscorea sativa L. = *Dioscorea villosa* L.	Dioscoreaceae	Kath Alu (Assamese); Kadia Kand, Mano Kand, Vaj Kand, Kadawa Kand, Kedvo Kand (Bombay Presidency)	Tubers are eaten cooked as vegetable by boiling or toasting. After neutralising toxic substances, the tuber may be mixed with *konda* or some other flours and then eaten	Gammie (1902) and Patiri and Borah (2007)
Dioscorea schimperiana Hochst. ex Kunth	Dioscoreaceae	Yagniat (Kipsigis, Kenya)	Root tubers are eaten	Kabuye (1986)
Dioscorea stemonoides Prain & Burkill	Dioscoreaceae	Kungkwad (Thai Sakai)	Tuber is the main source of carbohydrate for the Sakai tribe in peninsular Thailand	Maneenoon et al. (2008)
Dioscorea tranversa R. Br.	Dioscoreaceae	Long Yam	Tuber is eaten raw or roasted, also aerial bulbils	Cribb and Cribb (1987), Wightman and Andrews (1989), Low (1989), and Harden (1993)
Dioscorea trifida L.f.	Dioscoreaceae	Indian Yam, Cush-Cush and Yampee	Tubers are eaten boiled, baked	Facciola (1990), Walter and Lebot (2007), and Codex (2014)
Dioscorea triphylla L. = *Dioscorea pentaphylla* L.	Dioscoreaceae	See *D. Pentaphylla*	Tubers are eaten in India (Deccan)	Watt (1908)
Dioscorea tuberosa Vell. = *Dioscorea cinnamomifolia* Hook.	Dioscoreaceae	NF	India (Garhwal Himalayas): tuber is eaten after repeated boiling, washing and baking	Gupta (1962)
Dioscorea wallichii Hook.f.	Dioscoreaceae	Rui Nihang (Assamese), Yarex (Thai Sakai)	Tuber is the main source of carbohydrate for the Sakai tribe in peninsular Thailand	Maneenoon et al. (2008)
Dioscoreophyllum cumminsii (Stapf) Diels	Menispermaceae	Guinea Potato, African Serendipity Berry,	Tubers are eaten like potato	Jansen (1999)
Dipcadi erythraeum Webb & Berthel.	Asparagaceae	Askanda	Bulb is rich in starch, source of vegetables for nomads	Gupta and Kanodia (1968b)
Dipodium atropurpureum D.L. Jones	Orchidaceae	Purple Hyacinth Orchid	Fleshy, starchy, thick roots are eaten	Harden (1993)

Dipodium hamiltonianum F.M. Bailey	Orchidaceae	Green Hyacinth Orchid	Fleshy, starchy, thick roots are eaten	Harden (1993)
Dipodium pulchellum D.L. Jones & M.A. Clem.	Orchidaceae	Dark Hyacinth Orchid	Fleshy, starchy, thick roots are eaten by aborigines	Harden (1993)
Dipodium punctatum (Sm.) R. Br. =*Dipodium squamatum* (G. Forst.) R. Br.	Orchidaceae	Hyacinth Orchid	Fleshy, starchy, thick roots are eaten by aborigines	Low (1989, 1991) and Harden (1993)
Dipodium roseum D.L. Jones & M.A. Clem.	Orchidaceae	Pink Hyacinth Orchid	Fleshy, starchy, thick roots are eaten	Harden (1993)
Dipodium spp.	Orchidaceae	Hyacinth Orchids	Fleshy, starchy, thick roots are eaten by aborigines	Cribb and Cribb (1987)
Dipodium variegatum M.A. Clem. & D.L. Jones	Orchidaceae	Spotted Hyacinth Orchid	Fleshy, starchy, thick roots are eaten	Harden (1993)
Disporopsis aspersa (Hua) Engler ex Krause	Asparagaceae	Golden Hematinic, Mottled False Disporum, Huang Jin Qi (Chinese)	Rhizomes are cooked with pork in central China	Hu (2005)
Disporopsis pernyi (Hua) Diels	Asparagaceae	Bamboo-Root Hematinic, Zhu Gen Qi (Chinese)	Rhizomes are cooked with chicken given as a special food for postpartum mothers in Guizhou	Hu (2005)
Diuris abbreviata F. Muell. ex Benth.	Orchidaceae	Lemon Doubletail	Fleshy, starchy, bland, glutinous, tubers are eaten	Harden (1993)
Diuris alba R. Br.	Orchidaceae	White Donkey Orchid	As above	Harden (1993)
Diuris aurea Sm.	Orchidaceae	Golden Donkey	Fleshy, starchy, bland, glutinous tubers are eaten	Low (1991)
Diuris chrysantha D.L. Jones & M.A. Clem.	Orchidaceae	Yellow Donkey Orchid	As above	Harden (1993)
Diuris dendrobioides Fitzg. = *Diuris punctata* Sm.	Orchidaceae	Purple Donkey Orchid	As above	Harden (1993)
Diuris goonooensis Rupp = *Diuris platichila* Fitzg.	Orchidaceae	Western Donkey Orchid	As above	Harden (1993)
Diuris lanceolata Lindl.	Orchidaceae	Snake Orchid, Golden Moths	As above	Harden (1993)
Diuris maculata Sm.	Orchidaceae	Leopard Orchid	Tubers are bland and glutinous	Low (1989, 1991)
Diuris pedunculata R. Br.	Orchidaceae	Golden Moths, Small Snake Orchid	As above	Harden (1993)
Diuris punctata Sm.	Orchidaceae	Purple Donkey Orchid	As above	Harden (1993)

(continued)

Table 1 (continued)

Diuris striata Rupp	Orchidaceae	NF	As above	Harden (1993)
Diuris sulphurea R. Br.	Orchidaceae	Tiger Orchid, Hornet Orchid	As above	Harden (1993)
Diuris tricolor Fitzg.	Orchidaceae	Tricolor Donkey Orchid	As above	Harden (1993)
Diuris venosa Rupp	Orchidaceae	Veined Doubletail, Veined Donkey Orchid, Goat Orchid	As above	Harden (1993)
Dolichos biflorus L. = *Vigna unguilata* (L.) Walp.	Fabaceae	Horse Gram	In Australia (North Queensland), rootstock is roasted and eaten	Watt (1908) and Irvine (1957)
Doryanthes excelsa Corrêa	Doryanthaceae	Gymea Lily	Hefty roots are eaten	Low (1989) and Lim (2014)
Dracontium polyphyllum L.	Araceae	Kaat Curna (Tamil), Adive Kanda (Telugu)	Cooked tubers are eaten	Watt (1908)
Drosera auriculata Backh. ex Planch.	Droseraceae	Climbing Sundew	Tubers may be edible	Harden (1990)
Drynaria baronii (Christ) Diels = *Drynaria sinica* Diels	Polypodiaceae	Qin Ling Hu Jue (Chinese)	Rhizome is source of starch	Dai et al. (2003) and Cao et al. (2007)
Drynaria fortunei (Kunze ex Mett.) J. Sm. = *Drynaria roosii* Nakaike	Polypodiaceae	Hu Jue (Chinese)	Rhizome starch is used for cakes and liquor	Dai et al. (2003), Cao et al. (2007), and Yun et al. (2009b)
Dryopteris dilatata (Hoffm.) A. Gray	Dryopteridaceae	Shield Fern	Root is eaten	Schofield (2003)
Echinophora spinosa L.	Apiaceae	Prickly Samphire, Sea Parsnip	Roots are edible with a parsnip flavour	Hedrick (1972) and Facciola (1990)
Eleocharis dulcis (Brrm.f.) Trinius ex Henscel	Cyperaceae	Water Chestnut, Ground Chestnut	Corms are eaten raw or fresh or from canned material, used in salad or as snack and as a condiment and pickled and also baked, go well in soups, stir-fries, dumplings or as garnish for vegetable dishes. Starch obtained from tubers for domestic use, mixed with sugar to prepare a refreshing morning drink as well as for pastry	Cribb and Cribb (1987), Low (1989), Facciola (1990), Phillips and Rix (1993), Paisooksantivatana (1966), Hu (2005), van Wyk (2006), Santich et al. (2008), and Codex (2014)
Eleocharis kuroguwai Ohwi	Cyperaceae	Kuro Gawai (Japanese)	Corm is edible	Codex (2014)
Eleusine indica (L.) Gaertn.	Poaceae	Indian Goosegrass, Wiregrass, Crowfootgrass	Roots are edible raw	Kunkel (1984)
Eleutherococcus senticosus (Rupr. & Maxim.) Harms	Araliaceae	Eleuthero Root, Siberian Ginseng, Ci Wu Jia (Chinese)	Root and stem are used for tea	Hu (2005)
Emex spinosa (L.) Campd.	Polygonaceae	Devil's Thorn	Roots are eaten raw or cooked	Kunkel (1984) and Facciola (1990)

Ensete superbum (Roxb.) Cheesman	Musaceae	Dwarf Banana, Red Dwarf Banana, Cliff Banana, Lobong Ken-Tong (Assamese)	Rhizome is eaten in Karbi, Assam	Kar and Borthakur (2008)
Ensete ventricosum (Welw.) Cheesman	Musaceae	Abyssinian Banana	Rhizome is eaten	Codex (2014)
Epilobium angustifolium L.	Onagraceae	Fireweed	Norway: a flour is obtained from the roots which is baked into flat cakes	Sayce (1953) and Uphof (1968)
Eriochilus cucullatus (Labill.) Rchb.f.	Orchidaceae	Smooth Leaf Parson's Bands, Large Parson's Bands	Egg-shaped tubers are eaten	Low (1991) and Harden (1993)
Eriophorum gracile Koch	Cyperaceae	Mousenuts, Alaska Cotton, Swamp Cotton	Rootstock is used raw or cooked	Schofield (2003)
Eriophyton wallichii Benth. ex Wall.	Lamiaceae	Mian Shen (Chinese)	Roots are used in food in northwestern Yunnan	Hu (2005)
Eriosema chinense Vogel	Fabaceae	Chinese Eriosoma, Katil (Indonesia)	Tubers are eaten cooked; enlarged fleshy tuberous roots are used in tonifying broth with pork	Cribb and Cribb (1987), Groen et al. (1996), and Hu (2005)
Erodium crinitum Carolin	Geraniaceae	Smooth Leaf Parson's Bands, Large Parson's Bands	Rhizomes are edible cooked	Cribb and Cribb (1987) and Harden (1992)
Eryngium campestre L.	Apiaceae	Snakeroot	Roots are cooked as vegetables. Candied roots are eaten in England and France	Uphof (1968), Tanaka (1976), and Facciola (1990)
Eryngium maritimum L.	Apiaceae	Sea Holly, Sea Eryngo	Roots boiled or roasted resembled chestnuts or parsnips in taste. Roots are candied	Grieve (1971), Hedrick (1972), and Facciola (1990)
Erythrina vespertilio Benth.	Fabaceae	Bat's Wing Coral Tree	Roots are eaten raw by aborigines	Cribb and Cribb (1987)
Erythronium americanum Ker Gawl.	Liliaceae	Trout Lily, Yellow Adder's Tongue	Bulbs are eaten raw, boiled or roasted	Harrington (1974), Gibbons and Tucker (1979), and Facciola (1990)
Erythronium albidum Nutt.	Liliaceae	White Trout Lily	Bulbs are eaten boiled	Gibbons and Tucker (1979) and Facciola (1990)
Erythronium dens-canis L.	Liliaceae	Dog's Tooth Violet	Roots are eaten with reindeer or cow's milk in Siberia and Mongolia. Also a source of starch used in vermicelli and cakes	Hedrick (1972), Uphof (1968), and Facciola (1990)

(continued)

Table 1 (continued)

Erythronium japonicum Decne.	Liliaceae	Katakuri	Bulbs are source of starch used in dumplings, confectionery, fritters to thicken soups or as dietetic food	Tanaka (1976) and Facciola (1990)
Erythronium oregonum Applegate	Liliaceae	Fawn Lily, White Fawn Lily	Bulb is eaten raw, boiled or roasted	Facciola (1990)
Eucalyptus caesia Benth.	Myrtaceae	Caesia, Gungurru, Silver Princes	Bark of young roots is eaten	Cribb and Cribb (1987)
Eucalyptus dumosa A. Cunn. ex Oxley	Myrtaceae	Water Mallee, Congoo Mallee, White Mallee	As above	Cribb and Cribb (1987) and Facciola (1990)
Eucalyptus loxophleba Benth.	Myrtaceae	Smooth-Barked York Gum, York	Root bark is eaten	Low (1989)
Euryale ferox Salisb.	Nymphaeaceae	Chicken Head, Fox Nut	In China, roots and seeds are eaten	Read (1946) and Facciola (1990)
Eurycoma longifolia Jack	Simaroubaceae	Tongkat Ali (Malay)	Traditional users of tongkat ali brew tea from the dried chips of the tree's root. Tea, coffee and carbonated beverages, premixed with the root extract, are available commercially for the improvement of general health and libido in Malaysia	Low et al. (2013)
Eustrephus latifolius R. Br.	Asparagaceae	Wombat Berry	Root tuber crisp is eaten raw	Cribb and Cribb (1987)
Eutrema wasabi Maxim. = *Eutrema japonicum* (Miq.) Koidz.	Brassicaceae	Wasabi, Asian Horseradish	Root is used as spice	Facciola (1990) and Hu (2005)
Farfugium japonicum var. *formosanum* (Hayata) Kitamura	Asteraceae	Leopard Plant, Green Leopard Plant, Gao Wu (Chinese)	Roots are eaten in Taiwan	Hu (2005)
Ferula assa-foetida L.	Apiaceae	Asafoetida	Gum extracted from stem and roots is used as condiment in food and has a garlic flavour	Facciola (1990) and Jansen (1999)
Fimbristylis kysoor (Roxb.) Dalz. & Gibbs	Cyperaceae	NF	Root is eaten in India	Watt (1908)
Fimbristylis subbispicata Nees = *Fimbristylis tristachya* var. *subbispicata* (Nees) T. Koyama	Cyperaceae	Sedge, Pond Onion	Shoots and roots are eaten in China	Read (1946)
Flemingia procumbens Roxb.	Fabaceae	Sohplong (India)	Starch rib tubers are eaten raw	Groen et al. (1996)
Flemingia vestita Baker = *Flemingia procumbens* Roxb.	Fabaceae	Soh Phlang	Tuber is eaten in Meghalaya	Sawian et al. (2007)

Fockea angustifolia K. Schum.	Apocyanaceae	Water Root, Khoa	Swollen rootstock is eaten raw when young or used for making jam and preserved in South Africa	Fox et al. (1982) and Facciola (1990)
Fockea edulis (Thunb.) K. Schum.	Apocyanaceae	Kambro	Large tuber is used to make a konfyt as an alternative to watermelon	Fox et al. (1982) and Facciola (1990)
Foeniculum azoricum Mill. = *Foeniculum vulgare* Mill.	Apiaceae	Florentine, Florence	Swollen bulbs of leaf bases are eaten raw as accompaniment to cheese or cooked	Phillips and Rix (1993)
Foeniculum vulgare Mill.	Apiaceae	Fennel	Thick roots of young plants are cooked and eaten	Facciola (1990) and Phillips and Rix (1993)
Fritillaria camschatcensis (L.) Ker Gawl.	Liliaceae	Indian Rice, Black Lily, Kamchatka Fritillary, Chocolate Lily, Rice-of-the-Earth	Bulbs are eaten raw or cooked, steamed with garlic butter or a spicy sauce, boiled, mashed, stir-fried and top with butter, brown sugar, herbs or sauces and added to casseroles. Bulbs are also made into soups or a meal in itself. Bulb is dried and ground for flour. Bulblets are eaten as food	Facciola (1990), Schofield (2003), and Hu (2005)
Fritillaria lanceolata Torr. = *Fritillaria biflora* var. *biflora*	Liliaceae	Mission Bells	As above	Schofield (2003)
Fritillaria pudica (Pursh) Spreng.	Liliaceae	Yellow Bells	As above	Schofield (2003)
Fritillaria verticillata Willd.	Liliaceae	Baimo	Bulbs are eaten fried or candied in China	Tanaka (1976) and Facciola (1990)
Fumaria bulbosa L. = *Corydalis solida* (L.) Clairv.	Papaveraceae	NF	In France, starch of root is recommended as famine food for extending bread flour, after removal of bitter element	Parmentier (1781) (cited by Freedman 2009)
Galactia tenuiflora (Willd.) Wight & Arn.	Fabaceae	Florida Hammock Milkpea	Root is eaten after treatment	Cribb and Cribb (1987)
Gastrodia elata Blume	Orchidaceae	Gastrodia Tuber, Tian Ma (Chinese)	Fleshy potato-like tuber is boiled in water for tea or with chicken in soup	Hu (2005) and Codex (2014)
Gastrodia procera G.W. Carr	Orchidaceae	Large Potato Orchid, Large Cinnamon Bells	Tuber is edible and reportedly formed as mainstay diet for the Tasmanian aborigines. The cooked tuber is described as 'like beetroot'	Harden (1993)
Gastrodia sesamoides R. Br.	Orchidaceae	Potato Orchid, Cinnamon Bells	As above	Cribb and Cribb (1987) and Low (1989, 1991)

(continued)

Table 1 (continued)

Genoplesium archeri (Hook.f.) D.L. Jones & M.A. Clem.	Orchidaceae	Variable Midge Orchid	Tubers are edible	Harden (1993)
Genoplesium filiforme (Fitzg.) D.L. Jones & M.A. Clem	Orchidaceae	Glandular Midge Orchid	Tubers are edible	Harden (1993)
Genoplesium fimbriatum (R. Br.) D.L. Jones & M.A. Clem.	Orchidaceae	Fringed Midge Orchid	Tubers are edible	Harden (1993)
Genoplesium nudiscapum (Hook.f.) D.L. Jones & M.A. Clem.	Orchidaceae	Dense Midge Orchid	Tubers are edible	Harden (1993)
Genoplesium nudum (Hook.f.) D.L. Jones & M.A. Clem.	Orchidaceae	Tiny Midge Orchid	Tubers are edible	Harden (1993)
Genoplesium pedersonii D.L. Jones	Orchidaceae	Red Midge Orchid	Tubers are edible	Harden (1993)
Genoplesium rufum (R. Br.) D.L. Jones & M.A. Clem.	Orchidaceae	Red Midge Orchid	Tubers are edible	Harden (1993)
Geodorum sp.	Orchidaceae	Ground Gem Orchid	Tubers are eaten by aborigines	Cribb and Cribb (1987)
Geranium solanderi Carolin	Geraniaceae	Native Cranebills, Native Geranium	Starchy taproots eaten after roasting have a turnip flavour	Cribb and Cribb (1987), Low (1989, 1991), and Harden (1992)
Gladiolus byzantinus Mill. = *Gladiolus communis* L.	Iridaceae	Byzantine Gladiolus	In France, starch of root is recommended as a famine food for extending bread flour, after removal of bitter element	Parmentier (1781) (cited by Freedman 2009)
Glossodia major R. Br.	Orchidaceae	Common Wax Lip	Tubers are watery and bittersweet when eaten	Low (1991) and Harden (1993)
Glossodia sp.	Orchidaceae	Waxlip Orchids	Tubers are eaten by aborigines	Cribb and Cribb (1987)
Glottiphyllum linguiforme (L.) N.E. Br.	Aizoaceae	Tongue Leaf Plant	Roots are used in Transvaal for making a fermented beer	Fox et al. (1982) and Facciola (1990)
Glycyrrhiza glabra L.	Fabaceae	Licorice, Liquorice	Pieces of rhizomes are used as flavourant or sweetener, can be chewed as sweet snack used in confectionery, sweets, drinks, dark beers (stouts) and liqueurs	van Wyk (2006)
Glycyrrhiza lepidota Pursh	Fabaceae	American Licorice	Roots are chewed, added to other foods for flavouring or dried and brewed in tea	Uphof (1968), Fernald et al. (1958), and Facciola (1990)
Gynura bicolor (Roxb. ex Willd.) DC.	Asteraceae	Red Groundsel, Di Huang Cai (Chinese)	Roots are cooked with sliced pork	Hu (2005)

Gypsophila davurica Turcz. ex Fenzl	Caryophyllaceae	Cao Yuan Shi Tou Hua (Chinese)	In Manchuria (eastern forests), root is eaten after thorough processing. Contains toxic saponin	Baranov (1967)
Habenaria conopsea Rchb.f.	Orchidaceae	Fragrant Orchid, Shou Shen (Chinese)	Tuber is used in soup with meat	Hu (2005)
Habenaria delavayi Finet	Orchidaceae	Ji Zhu Shen, Chi Chua Shen (Chinese)	Tubers are eaten by ethnic group in Yunnan	Hu (2005)
Habenaria multipartite Blume ex Kraenzl.	Orchidaceae	Toothed Habenaria	Tubers are used as emergency food	Groen et al. (1996)
Habenaria rumphii (Brong.) Lindl.	Orchidaceae	NF	Tubers are used as emergency food	Groen et al. (1996)
Habenaria sparsiflora S. Watson = *Platanthera sparsiflora* (S. Watson) Schltr.	Orchidaceae	Bog Orchid	North America (New Mexico): bulb is used by Native American San Felipe Pueblo group in times of food shortage	Yanovsky (1936) and Castetter and Bell (1942)
Haemodorum corymbosum Vahl	Haemodoraceae	Bloodroot	Bulb is eaten after roasting	Cribb and Cribb (1987)
Haemodorum sp.	Haemodoraceae	Bloodroot	Roots are pounded and cooked	Low (1989)
Halopegia blumei (Körn.) K. Schum.	Marantaceae	Jelantir (Javanese), Patat (Sundanese), Dong Nam (Vietnam)	Tubers are eaten cooked or roasted	Groen et al. (1996) and Ochse and van den Brink (1980)
Hardenbergia retusa Benth. = *Vandasina retusa* (Benth.) Rauschert	Fabaceae	Sarsaparilla Vine	Roots are roasted	Cribb and Cribb (1987)
Hedychium coronarium J. Koenig	Zingiberaceae	White Ginger Lily	Tubers are eaten in India (Deccan)	Watt (1908) and Lim (2014)
Hedysarum boreale Nutt.	Fabaceae	Licorice Root, Sweet Root	Young sweet roots have a licorice flavour and are eaten raw, boiled, baked or added in soups	Uphof (1968), Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Hedysarum mackenzii Richardson = *Hedysarum boreale* subsp. *mackenzii* (Richardson) S.L. Welsh	Fabaceae	Licorice Root, Sweet Broom	Young sweet roots have a licorice flavour and are eaten	Uphof (1968), Hedrick (1972), Fernald et al. (1958), and Facciola (1990)
Hedysarum occidentale Greene	Fabaceae	Licorice Root, Sweet Vetch	As above	Facciola (1990)
Helianthus annuus L.	Asteraceae	Sunflower, Xiang Ri Kui (Chinese)	Root is used for tea	Hu (2005)
Helianthus maximiliani Schrad.	Asteraceae	Maximilian Sunflower	Tubers may be eaten raw, boiled or roasted	Yanovsky (1936) and Facciola (1990)
Helianthus strumosus L. = *Helianthus hirsutus* Raf.	Asteraceae	Paleleaf Woodland Sunflower	Used raw or cooked like the Jerusalem artichoke	Kunkel (1984)

(continued)

Table 1 (continued)

Helianthus tuberosus L.	Asteraceae	Jerusalem Artichoke, Girosole	Tubers are boiled and used as vegetables – raw in salads or lightly cooked in stir-fries or as a vegetable served with cream, butter or a sauce. Sliced rhizomes are fried as fritter and made into soufflés or purees. Tubers are rich source of inulin and sugar	Saunders (1920), Kaldy et al. (1980), Facciola (1990), Phillips and Rix (1993), Vervelde (1996), Cabezas et al. (2002), Hu (2005), van Wyk (2006), Santich et al. (2008), and Codex (2014)
Helianthus x laetiflorus Pers.	Asteraceae	Showy Sunflower	Tubers are edible	Gibbons and Tucker (1979) and Facciola (1990)
Helleborus niger L.	Ranunculaceae	Christmas Rose, Black Hellebore	In France, starch of root is recommended for extending bread flour, after removal of bitter element	Parmentier (1781) (cited by Freedman 2009)
Hemerocallis fulva (L.) L.	Xanthorrhoeaceae	Orange Day Lily, Tawny Daylily, Shina-Kanzo (Japanese)	In China, flowers, leaves, shoots and roots are eaten. Root can be prepared into flour from which cakes are made. Bulbs are boiled and creamed, baked eaten raw, mashed or made into fritters	Read (1946), Harrington (1974), Tanaka (1976), Facciola (1990), and Lim (2014)
Hemerocallis lilioasphodelus L.	Xanthorrhoeaceae	Yellow Day Lily, Lemon Lily, Wasuregusa (Japanese)	Fleshy root boiled in salt water tastes like blend of sweet corn and salsify	Fernald et al. (1958), Facciola (1990), and Lim (2014)
Hemerocallis minor Mill.	Xanthorrhoeaceae	Grassleaf Daylily, Hosoba-Kisuge (Japanese)	Bulbs are baked, steamed, roasted or stir-fried in Japan and China	Hedrick (1972), Tanaka (1976), and Facciola (1990)
Heracleum lanatum Michx.	Apiaceae	Cow Parsnip	Cooked root has a flavour like rutabaga	Facciola (1990)
Heracleum sphondylium subsp. *montanum* (Schleich. ex Gaudin) Briq.	Apiaceae	American Cow Parsnip		Harrington (1974), Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Heuchera glabra Willd. ex Roem. & Schult.	Saxifragaceae	Alpine Heuchera, Smooth Heuchera	Roots are edible and chopped and added to soups and vegetable pies	Schofield (2003)
Heuchera micrantha Douglas ex Lindl.	Saxifragaceae	Small-Flowered Alum Root	As above	Schofield (2003)
Hibiscus divaricatus Graham	Malvaceae	Native Hibiscus	In Australia (South Australia, northeast; Queensland, north), roots and buds of young plants are eaten raw	Irvine (1957)
Hibiscus diversifolius Jacq.	Malvaceae	Swamp Hibiscus	Young starchy roots are eaten	Cribb and Cribb (1987)
Hibiscus heterophyllus Vent.	Malvaceae	Native Rosella Queensland Sorrel, Green Kurrajong, Batham; New South Wales, Dtharang-Gange	Young starchy roots are eaten in Australia	Maiden (1889), Cribb and Cribb (1987), and Harden (1990)

Hibiscus sturtii Hook.	Malvaceae	Hill Hibiscus	As above	Harden (1990)
Hibiscus tiliaceus L.	Malvaceae	Beach Hibiscus, Cuan Bast, Huang Jin (Chinese)	Roots are eaten by fishing community along the coast of South China Sea	Hu (2005)
Hibiscus trionum L.	Malvaceae	Flower-of-an-Hour, Bladder Hibiscus, Bladder Ketmia, Bladder Weed	Starchy root is eaten	Harden (1990)
Homalomena aromatica (Spreng.) Schott	Araceae	Ok Hi Atehang; Tharem, Thagong-Yungsa (Assamese)	Tuber is eaten in Karbi, Assam	Kar and Borthakur (2008) and Medhi and Borthakur (2012)
Hordeum bulbosum L.	Poaceae	Abu Suwaif	Bulbous roots are chewed and eaten occasionally	Tanaka (1976) and Facciola (1990)
Hornstedtia scottiana (F. Muell.) K. Schum.	Zingiberaceae	Jiddo, Scotts Ginger	Tuberous root is eaten edible	Wikipedia (2014)
Hosta plantaginea (Lam.) Asch.	Asparagaceae	Plantain Lily, Yu Zan (Chinese)	Root is cooked with meat in Hubei	Hu (2005)
Houttuynia cordata Thunb.	Saururaceae	Heart-Leaved Houttuynia, Fishwort; Masundari, Mosondoi (Assamese); Maisundri (Bodo)	Roots are edible, eaten as chutney. It is used in various Assamese dishes	Uphof (1968), Tanaka (1976), Facciola (1990), and Patiri and Borah (2007)
Humulus lupulus L.	Cannabaceae	Hops	Fleshy rhizomes are sometimes eaten	Uphof (1968), Kunkel (1984), and Facciola (1990)
Humulus lupulus var. *cordifolius* (Miq.) Maxim. ex Franch. & Sav. = *Humulus lupulus* L.	Cannabaceae	Hops	Fleshy rhizomes are sometimes eaten	Facciola (1990)
Hydrophyllum canadense L.	Boraginaceae	John's Cabbage, Bluntleaf Waterleaf	Root is eaten in times of famine	Yanovsky (1936) and Hedrick (1972)
Hyoscyamus vulgaris Neck.	Solanaceae	NF	In France, starch of root is recommended as famine food for extending bread flour, after removal of bitter element	Parmentier (1781) (cited by Freedman 2009)
Hypoxis hygrometrica Labill.	Hypoxidaceae	Golden Stars, Star Grass, Golden Weather-Glass	Roasted minute tubers are eaten by aborigines	Cribb and Cribb (1987) and Low (1991)
Hypoxis nervosa R.J.F. Hend.	Hypoxidaceae	Golden Stars, Star Grass	As above	Low (1991)
Hypoxis filiformis Baker	Hypoxidaceae	Isinongwe (Zulu)	In Zululand (Ubombo district), roots are boiled and eaten	Hely-Hutchinson (1898)
Hypoxis marginata R. Br.	Hypoxidaceae	Golden Stars, Star Grass	Roots are boiled and eaten	Low (1989)
Hypoxis pratensis R. Br.	Hypoxidaceae	Golden Stars, Star Grass	As above	Low (1991)

(continued)

Table 1 (continued)

Icacina mannii Oliver	Icacinaceae	Mutuo (Akan-Twi, Ghana), Akin (Kyama, Ivory Coast), Ututo Ogiri (Igbo, Nigeria)	Tubers are eaten after detoxification in Africa (area not specified)	Irvine (1952), Uphof (1968), and Ferry et al. (1974)
Icacina senegalensis Juss. = *Icacina oliviformis* (Poir.) J. Raynal	Icacinaceae	False African Yam	West Africa as above	Irvine (1952), Uphof (1968), Kay (1973), and Ferry et al. (1974)
Imperata cylindrica L.	Poaceae	Blady Grass, Alang-Alang, Lalang Wooly Grass	Aboriginal children sucked the roots, underground shoots like sugar cane, used as survival food; a kind of beer is made from the roots in peninsular Malaysia. China: fresh rhizome is chewed by rural people for the sweet juice	Burkill (1966), Cribb and Cribb (1987), Low (1991), and Hu (2005)
Imperatoria major Gray	Apiaceae	NF	France: starch of root is recommended for extending bread flour, after removal of bitter element	Parmentier (1781) (cited by Freedman 2009)
Ipomoea graminea R. Br.	Convolvulaceae	Bush Potato	Large tubers are roasted and eaten	Cribb and Cribb (1987)
Ipomoea racemosa Poir. = *Turbina racemosa* (Poir.) D.F. Austin	Convolvulaceae	Soh Lah	Tuber is eaten in Meghalaya	Sawian et al. (2007)
Ipomoea aquatica Forsk.	Convolvulaceae	Water Spinach, Kangkong, River Spinach, Water Morning Glory	Roots are occasionally cooked and eaten	Facciola (1990)
Ipomoea batatas (Linn.) Lam	Convolvulaceae	Sweet Potato, Phan Karo (Meghalaya), Ruidok (Assam)	Tuber is eaten in Meghalaya and in Karbi, Assam; sweet potatoes are always eaten cooked, boiled, baked, roasted or fried and work well in stews, soups and braised dishes	Burkill (1966), Facciola (1990), Phillips and Rix (1993), Takagi et al. (1996), Hu (2005), van Wyk (2006), Sawian et al. (2007), Walter and Lebot (2007), Kar and Borthakur (2008), Santich et al. (2008), and Codex (2014)
Ipomoea cairica (L.) Sweet	Convolvulaceae	Morning Glory, Mile-a-Minute Vine, Messina Creeper, Cairo Morning Glory, Coast Morning Glory; Wu Zhao Jin Long (Chinese)	Roots are used to extract starch in Yunnan	Hu (2005)
Ipomoea calobra F. Muell.	Convolvulaceae	Bush Potato, Goolabura	Large tubers are roasted and eaten	Cribb and Cribb (1987) and Low (1991)
Ipomoea costata F. Muell. ex Benth.	Convolvulaceae	Bush Potato, Desert Yam	As above	Low (1991)

Ipomoea digitata L. = *Ipomoea cheirophylla* O'Donell	Convolvulaceae	Spanish Woodbine	Oblong tubers are eaten like sweet potatoes	Hedrick (1972), Tanaka (1976), and Facciola (1990)
Ipomoea eriocarpa R. Br.	Convolvulaceae	Tiny Morning Glory; Buta (Hindi); Mulli Balli (Kannada)	Large tubers are roasted and eaten	Cribb and Cribb (1987)
Ipomoea gracilis R. Br.	Convolvulaceae	Almor-Ira	Large tubers are roasted and eaten	Cribb and Cribb (1987)
Ipomoea mauritiana Jacq.	Convolvulaceae	Giant Potato, Qi Zhao Long (Chinese)	Roots are used to extract starch	Hu (2005)
Ipomoea pandurata (L.) G. Meyer	Convolvulaceae	Wild Potato Vine, Man-of the-Earth	Huge, tuberous root weighing sometimes 20 lb	Saunders (1920)
Ipomoea pes-caprae subsp. *brasiliensis*	Convolvulaceae	Goatsfoot Convolvulus, Beach Morning Glory	Fleshy taproot is eaten after baking and pounding	Cribb and Cribb (1987)
Ipomoea polpha R.W. Johnson	Convolvulaceae	Bush Potato, Weir Vine	Large tubers are roasted and eaten	Low (1991)
Ipomoea polymorpha Roem. & Schult.	Convolvulaceae	Silky Cow Vine	Large tubers are roasted and eaten	Cribb and Cribb (1987)
Ipomoea staphylina Roem. & Schult.	Convolvulaceae	Lesser Glory, Hai Nan Shu (Chinese)	Fleshy tubers are eaten in Hainan island	Hu (2005)
Ipomoea velutina R. Br.	Convolvulaceae	Velvet Morning Glory	Large tubers are roasted and eaten	Cribb and Cribb (1987)
Ipomoea violacea L.	Convolvulaceae	Beach Moonflower, Sea Moonflower	Large tubers are roasted and eaten	Cribb and Cribb (1987)
Iris foetidissima L.	Iridaceae	Stinking Iris	France: starch of root is recommended as a famine food for extending bread flour, after removal of the bitter element	Parmentier (1781) (cited by Freedman 2009)
Iris lutea Lam. = *Iris pseudacorus* L.	Iridaceae	Yellow Flag, Yellow Iris, Water Flag Iris, Yellow Water Flag	As above	Parmentier (1781) (cited by Freedman 2009)
Iris pallida Lam.	Iridaceae	Sweet Iris	Dried rhizomes give an essential oil, orris oil, used to flavour soft drinks, candy and chewing gum. It is also chewed to sweeten the breath	Morton (1976) and Facciola (1990)
Iris setosa Pall. ex Link	Iridaceae	Beachhead Iris, Canada Beachhead Iris, Wild Flag	Rhizomes are eaten or used as source of starch	Uphof (1968), Hedrick (1972), Tanaka (1976), and Facciola (1990)
Iris vulgaris Pohl = *Iris x germanica* L.	Iridaceae	German Iris	As above	Parmentier (1781) (cited by Freedman 2009)

(continued)

Table 1 (continued)

Iris x germanica L.	Iridaceae	German Iris	Rhizomes are dried and used as flavouring or sometimes they are chewed	Uphof (1968), Morton (1976), and Facciola (1990)
Ixeris chinensis (Thunb. ex Thunb.) Nakai	Asteraceae	Shan Ku Mai, Nai Jiang Cai (Chinese)	Root is eaten in northwestern China	Hu (2005)
Ixora subsessilis Wall. ex G. Don	Rubiaceae	Dieng Jowat (Meghalaya), Nang Guo Long Chuan Hua (Chinese)	Flower, shoot and root are eaten in Meghalaya	Sawian et al. (2007)
Jaltomata procumbens (Cav.) J.L. Gentry	Solanaceae	Creeping False Holly, Jaltomate	Roots are eaten raw or boiled	Altschul (1973) and Facciola (1990)
Kaempferia galanga L.	Zingiberaceae	Cekur, Kencur	Rhizome is eaten as spice to flavour food	Burkill (1966), Ochse and van den Brink (1980), and Facciola (1990)
Kaempferia pandurata Roxb. = *Boesenbergia rotunda* (L.) Mansf.	Zingiberaceae	Kencur, Temu Putri, Kunir Putih, Ardong, Kunci Pepet	Rhizome is eaten as spice to flavour food in Java	Ochse and van den Brink (1980)
Kaempferia rotunda L.	Zingiberaceae	Round-Rooted Galangal Kencur, Temu Putri, Kunir Putih, Ardong, Kunci Pepet	Rhizome is eaten as spice to flavour food in Java	Burkill (1966), Ochse and van den Brink (1980), and Facciola (1990)
Khadia acutipetala (N.E. Br.) N.E. Br.	Aizoaceae	Khadi root, Khadiwortel (Afrikaans)	Roots are used by natives of Transvaal to prepare a fermented liquor called khadi	Fox et al. (1982) and Facciola (1990)
Labichea buettneriana F. Muell.	Fabaceae	NF	Roots are roasted	Cribb and Cribb (1987)
Lablab purpureus (L.) Sweet	Fabaceae	Bonavista Bean, Hyacinth Bean, Dolichos Bean, Seim Bean, Lablab Bean	Large, starchy root is edible	Hedrick (1972) and Facciola (1990)
Languas galanga (L.) Stuntz	Zingiberaceae	Greater Galangal, False Galangal Lengkuas, Languas	Rhizome is used as a spice	Burkill (1966), Morton (1976), and Phillips and Rix (1993)
Languas javanica (Blume) Burkill = *Alpinia javanica* Blume	Zingiberaceae	Puar Putih, Tepus Putih, Kantan Hutan	Rhizome is used as food, scentless and bitter	Burkill (1966)
Lapathum alpinum Lam.	Polygonaceae	Monk's Rhubarb	France: starch of root is recommended as a famine food, for extending bread flour, after removal of toxic element	Parmentier (1781) (cited by Freedman 2009)
Lapathum aquaticum Garsault = *Rumex hydrolapathum* Huds.	Polygonaceae	Great Water Dock	As above	Parmentier (1781) (cited by Freedman 2009)
Lapathum sylvestre Lam. = *Rumex obtusifolius* L.	Polygonaceae	Broad-Leaved Dock, Bitter Dock	As above	Parmentier (1781) (cited by Freedman 2009)

Lasia spinosa (L.) Thwaites	Araceae	Lasia; Phak Naam (Thai); Henru Ehong, Chusot (Assamese)	Tuber is eaten in Karbi, Assam	Van den Bergh (1994) and Kar and Borthakur (2008)
Lathyrus tuberosus L.	Fabaceae	Earthnut Pea, Tuberous Pea	France: root tuber is recommended as a famine food cooked or dried and reduced to flour for use in baking bread	Parmentier (1781) (cited by Freedman 2009), Hedrick (1972), Fernald et al. (1958), Facciola (1990), and Codex (2014)
Lavatera plebeia Sims	Malvaceae	Australian Hollyhock	Slender roots are eaten	Cribb and Cribb (1987) and Low (1989)
Leichardtia australis R. Br. = *Marsdenia australis* (R. Br.) Druce	Apocynaceae	Doubah	Roots are edible	Cribb and Cribb (1987) and Facciola (1990)
Leonurus sibiricus L.	Lamiaceae	Siberian Motherwort	In China, the roots are cooked with pork	Burkill (1966), Altschul (1973), Tanaka (1976), and Facciola (1990)
Leopoldia comosa (L.) Parl.	Asparagaceae	Grape Hyacinth, Cippolini (Italian)	Bulbs are eaten boiled with vinegar, pickled or added to omelette. Cooked bulbs are preserved in oil used in antipasto or as relish	Uphof (1968), Bianchini and Corbetta (1976), and Facciola (1990)
Lepidium latifolium L.	Brassicaceae	Dittander	Hot pungent root is used as horseradish substitute	Uphof (1968) and Facciola (1990)
Lepidium meyenii Walp.	Brassicaceae	Maca	Dried maca is cooked in water or milk and used to prepare a kind of sweet and aromatic porridge, *mazamorra*. The dried roots are eaten after boiling in water or milk and are sometimes mixed with honey and fruit for preparation of juices and addition of sugar cane rum for cocktails and other alcoholic beverages. Flour is also prepared from the dried roots for making bread and cookies	León (1964), Johns (1981), Tello et al.(1992), Hermann and Heller (1997), Ochoa (2001), Flores et al. (2003), and Codex (2014)
Lepironia articulata (Retz.) Domin	Cyperaceae	Grey Sedge	Underground stem is eaten. Rhizome is edible	Cribb and Cribb (1987) and Low (1989)
Levisticum officinale W.D.J. Koch	Apiaceae	Lovage	Roots are the source of oil of lovage, used for flavouring. Roots can be chopped and preserved in honey	Grieve (1971), Hedrick (1972), Morton (1976), and Facciola (1990)
Levisticum vulgare Reichb.	Apiaceae	NF	France: root is recommended as a famine food after cooking 'a grande eau'	Parmentier (1781) (cited by Freedman 2009)

(continued)

Table 1 (continued)

Lewisia rediviva Pursh	Montiaceae	Bitterroot	Boiling has the effect of dissipating the bitterness; and the white heart of the root, which is starchy and mucilaginous, is certainly nutritious	Saunders (1920), Harrington (1974), Gibbons and Tucker (1979), and Facciola (1990)
Ligusticum scoticum L.	Apiaceae	Scotch Lovage	Roots are chewed	Hedrick (1972), Fernald et al. (1958), Gibbons and Tucker (1979), and Facciola (1990)
Ligusticum sinense Oliver	Apiaceae	Chinese Lovage, Shan Yuan Sui (Chinese)	Root is used for tea	Hu (2005)
Ligusticum wallichii Franch. = *Ligusticum striatum* DC.	Apiaceae	Sichuan Lovage, Chuan Xiong (Chinese)	Thin slices of dried root are used in bupin mixtures	Hu (2005)
Lilium amabile Palib.	Liliaceae	Friendly Lily, Koma Yuri (Japanese)	Bulbs are cooked and eaten as vegetable in Korea	Tanaka (1976) and Facciola (1990)
Lilium auratum Lindl.	Liliaceae	Goldband Lily, Yama-Yuri (Japanese)	Mucilaginous bulb is boiled, sweetened, powdered and used in dumplings or in a Japanese dish with eggs	Hedrick (1972), Altschul (1973), Tanaka (1976), and Facciola (1990)
Lilium auratum var. *platyphyllum* Baker	Liliaceae	Saku-Yuri (Japanese)	As above	Tanaka (1976)
Lilium brownii F.E. Br. ex Miellez	Liliaceae	White Lily, Hong Kong Lily, Paak-Hop (Chinese)	Bulbs are used fresh or dried; starch is obtained from the bulbs. Bulbs are also eaten baked or grated and added to thicken soup. In China, bulbs are eaten boiled in honey or dried and made into flour	Uphof (1968), Phillips and Rix (1993), Facciola (1990), and Hu (2005)
Lilium davidii Duch. ex Elwes	Liliaceae	David's Lily	Bulbs are eaten	Phillips and Rix (1993)
Lilium japonicum Thunb.	Liliaceae	Bamboo Lily	China: bulb is eaten	Read (1946)
Lilium lancifolium Thunb.	Liliaceae	Tiger Lily, Pai Ho (Chinese), Oniyuri (Japanese)	Fleshy scales of bulb are eaten fresh or dried	Facciola (1990), Hu (2005), and Phillips and Rix (1993)
Lilium longiflorum Thunb.	Liliaceae	White Trumpet Lily, Regal Lily, Teppo Yuri (Japanese)	Starch is obtained from the bulb	Tanaka (1976) and Facciola (1990)
Lilium superbum L.	Liliaceae	American Turk's-Cap Lily	Fleshy bulb is eaten cooked, also used for thickening soup	Hedrick (1972) and Facciola (1990)
Liriope spicata Lour.	Asparagaceae	Black Leek	China: mucilaginous tuber is eaten	Read (1947)
Litsea cubeba (Lour.) Pers.	Lauraceae	Mountain Pepper, May Chang (Chinese)	Roots are cooked with pork	Altschul (1973), Morton (1976), and Facciola (1990)

Lomatium californicum (Nutt.) Mathias & Constance	Apiaceae	Wild Celery Parsley	Aromatic roots are eaten by American Indians	Facciola (1990)
Lomatium dissectum (Nutt.) Mathias & Constance	Apiaceae	Fern-Leaved Biscuit Root	Roots are dried and cooked	Yanovsky (1936) and Facciola (1990)
Lomatium macrocarpum (Hook. & Arn.) J.M. Coult. & Rose = *Lomatium hallii* (S. Watson) J.M. Coult. & Rose	Apiaceae	Large-Fruited Biscuit Root	Roots eaten raw or dried and ground into flour to make cakes	Yanovsky (1936) and Facciola (1990)
Lomatium nudicaule (Pursh) J.M. Coult. & Rose = *Cogswellia nudicaulis* M.E. Jones	Apiaceae	Cow Parsley, Smyrnium	Roots are sometimes cooked and eaten	Yanovsky (1936), Hedrick (1972), and Facciola (1990)
Lotus siloquosus L.	Fabaceae	NF	France: farinaceous root is recommended as a famine food	Parmentier (1781) (cited by Freedman 2009)
Lunaria annua L.	Brassicaceae	Honesty	Roots can be eaten raw in salads	Uphof (1968), Hedrick (1972), and Facciola (1990)
Lupinus arcticus S. Watson	Fabaceae	Arctic Lupine	Roots are used as survival food after roasting	Schofield (2003)
Lupinus nootkatensis Sims	Fabaceae	Nootka Lupin	As above	Schofield (2003)
Lycopus europaeus L.	Lamiaceae	Gypsywort, Water Horehound	China: root is eaten. Manchuria: starchy tubers are eaten	Read (1946) and Baranov (1967)
Lycopus lucidus Turcz. ex Benth.	Lamiaceae	Lycopus, Bugleweed, Di Gua Er Miao (Chinese)	Underground rhizomes are eaten in northern China and Yunnan	Hu (2005)
Lycopus uniflorus Michx.	Lamiaceae	Northern Bugleweed	White tubers are eaten raw in salads, boiled, pickled or added to soups and stews	Fernald et al. (1958) and Facciola (1990)
Lycoris aurea (L'Hér.) Herb.	Amaryllidaceae	Lycoris	Roots are eaten in China	Read (1946)
Lycoris radiata (L'Hér.) Herb.	Amaryllidaceae	Red Spider Lily, Red Magic Lily	As above	Read (1946)
Lygodium microphyllum (Cav.) R. Br.	Lygodiaceae	Climbing Maidenhair	Slender fleshy underground stem is eaten	Cribb and Cribb (1987)
Lyperanthus sp.	Orchidaceae	Brown Beaks	Tubers are eaten by aborigines	Cribb and Cribb (1987)
Lyperanthus suaveolens R. Br.	Orchidaceae	Brown Beaks	Tubers are juicy fragrant	Low (1991)
Macrotyloma uniflorum (Lam.) Verd.	Fabaceae	Madras Gram, Horse Gram	Fleshy root is roasted and eaten by aborigines in Australia	Cribb and Cribb (1987) and Facciola (1990)

(continued)

Table 1 (continued)

Manihot esculenta Crantz	Euphorbiaceae	Cassava, Manioc, Tapioca, Yuca	Tuberous roots are eaten boiled, fried, baked, roasted and processed into flour, farina, sweetmeats, bread, syrup, pasties, fufu, chips, pastries and cakes. Flour is also used for thickening soups and sauces. Root sap is boiled to make the condiment cassareep or fermented into chicha and other alcoholic beverages	Burkill (1966), Uphof (1968), Hedrick (1972), Tanaka (1976), Ochse and van den Brink (1980), Facciola (1990), Veltkamp and De Bruijn (1996), and Hu (2005)
Manihot glaziovii Müll. Arg. = *Manihot carthaginensis* subsp. *glaziovii* (Müll. Arg.) Allem	Euphorbiaceae	Manicoba, Mandioca Brava, Ceara Rubber	Tubers are eaten sometimes, also a source of starch	Tanaka (1976) and Facciola (1990)
Manihot utilissima Pohl = *Manihot esculenta* Crantz	Euphorbiaceae	Cassava, Bitter Cassava; Ingwese, Aloti (Gabon); Bafra (Arabic, Sudan)	As for *M. esculenta*	Ochse and van den Brink (1980), Abdelmuti (1991), Burkill (1966), and Codex (2014)
Maranta arundinacea L.	Marantaceae	Arrowroot, Tora Alu (Assamese), Khaita Alu (Boro) Nginti Ali (Mishing) Arrowroot, Tha Lairusa, Hnathel, Hpogimbai	Rhizomes are source of arrowroot, eaten cooked or raw. Tuber is eaten both raw and boiled; starch is from rhizome	Ochse and van den Brink (1980), Facciola (1990), Villamayor and Jukema (1996), Hu (2005), Patiri and Borah (2007), Medhi and Borthakur (2012), and Codex (2014)
Maranta dichotoma (Roxb.) Wall. = *Schumannianthus dichotomus* (Roxb.) Gagnep.	Marantaceae	Mohtra Reed, Sitalpati Plant; Tha Lairu, Hnathel, Hpogimbai (Assamese)	Tuber is eaten both raw and boiled	Medhi and Borthakur (2012)
Marattia salicina Sm. = *Ptisana salicina* (Sm.) Murdock	Marattiaceae	Giant Fern, King Fern	Roots are edible	Cribb and Cribb (1987)
Mariscus sieberianus Nees ex C.B. Clarke = *Cyperus cyperoides* (L.) Kuntze	Cyperaceae	Tall Sedge	In China, roots and seeds are made into flour	Read (1946)
Marsdenia flavescens A. Cunn. = *Pergularia flavescens* (A. Cunn.) Hook.f. ex D. Dietr.	Apocyanaceae	Yellow Milk Vine, Native Potato	Tuberous root is eaten after preparation	Cribb and Cribb (1987) and Harden (1992)
Marsdenia viridiflora R. Br. = *Pergularia viridiflora* (R. Br.) Spreng.	Apocyanaceae	Bush Banana	Juicy insipid tubers are eaten	Low (1991) and Harden (1992)
Matteuccia pensylvanica (Willd.) Raymond = *Matteuccia struthiopteris* (L.) Tod.	Onocleaceae	Ostrich Fern	Rootstock is eaten boiled or roasted	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)

Matteuccia struthiopteris (L.) Tod.	Onocleaceae	Ostrich Fern, Jia Guo Jue (Chinese)	As above. In China, rhizome starch is used for noodle making	Cui (1998), Dai et al. (2003), Schofield (2003), and Cao et al. (2007)
Medeola virginiana L.	Liliaceae	Indian Cucumber Roots	Crisp, white rhizome is eaten raw as nibble, boiled and served with butter and mixed into tossed salads dressed with oil and vinegar or made into dill pickles	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Melampyrum roseum Maxim.	Orobanchaceae	Asian Cow Wheat, Shan Luo Huo (Chinese)	Roots are used for tea in northwestern China	Hu (2005)
Melilotus albus Medik.	Fabaceae	Sweet Clover	Roots are prized as food by some native groups in North America	Schofield (2003)
Melilotus officinalis (L.) Pall.	Fabaceae	Yellow Sweet Clover	As above	Facciola (1990) and Schofield (2003)
Menyanthes palustris S.F. Gray	Menyanthaceae	Bog Grass	France: root is recommended as a famine food after cooking and seasoning	Parmentier (1781) (cited by Freedman 2009)
Menyanthes trifoliata L.	Menyanthaceae	Buckbean, Marsh Clover, Marsh Trefoil, Bitter Worm, Water Shamrock	Great Britain, Norway: roots are leached to remove bitter element and then ground to a flour. Bitter rhizome is cooked as emergency food	Sayce. (1953), Facciola (1990), and Schofield (2003)
Merremia hungaiensis (Lingelsh. & Borza) R.C. Fang	Convolvulaceae	Huang Hua Tu Gua, Shan Tu Gua (Chinese)	Enlarged root is eaten in Yunnan	Hu (2005)
Mertensia maritima (L.) Gray	Boraginaceae	Sea Bugloss, Oyster Plant	Rhizomes are eaten by Eskimos in Alaska	Uphof (1968) and Facciola (1990)
Meum athamanticum Jacq.	Apiaceae	Spignel, Meu, Baldmoney	Roots are eaten like parsnip in Scotland	Uphof (1968), Grieve (1971), Launert (1981), and Facciola (1990)
Microseris lanceolata (Walp.) Sch. Bip.	Asteraceae	Yam Daisy, Murnong, Native Yam	Tubers are eaten after roasting	Cribb and Cribb (1987)
Microseris scapigera (Sol. ex A. Cunn.) Sch. Bip.	Asteraceae	Yam Daisy, Murnong, Native Dandelion	Tubers are eaten after roasting	Cribb and Cribb (1987), Low (1989), and Codex (2014)
Microstemma tuberosum R. Br.	Apocyanaceae	White Turnip	Tubers are eaten raw or roasted	Cribb and Cribb (1987)
Microtis parviflora R. Br. = *Microtis unifolia* (G. Forst.) Rchb.f.	Orchidaceae	Slender Onion Orchid	As above	Harden (1993)
Microtis sp.	Orchidaceae	Onion Orchid	Tubers are bland starchy eaten by aborigines	Cribb and Cribb (1987) and Low (1991)

(continued)

Table 1 (continued)

Microtis unifolia (G. Forst.) Rchb.f.	Orchidaceae	Common Onion Orchid	As above	Harden (1993)
Millettia speciosa Champ. ex Benth.	Fabaceae	Showy Millettia, Shan Lian Ou (Chinese)	Root fresh or dried is boiled with pork for soup that strengthens bones used in southern China and Hong Kong	Hu (2005)
Mirabilis expansa (Ruiz & Pav.) Standl.	Nyctaginaceae	Mauka, Chago	Tuber is dried, boiled or fried, eaten as vegetable	Tanaka (1976), Popenoe et al. (1989), Facciola (1990), Bermejo and Leon (1994), and Codex (2014)
Moghania philippinensis (Merr. & Rolfe) Li = *Flemingia prostrata* Roxb.	Fabaceae	Southern Astragalus, Qian Jin Ba (Chinese)	Sliced roots are cooked with pig's feet in water and cooking wine, a special southern Chinese cuisine	Hu (2005)
Monochoria vaginalis (Burm.f.) C. Presl	Pontederiaceae	Duck Tongue Herb, Ya She Cao (Chinese)	China: young rhizome is eaten	Hu (2005)
Montia perfoliata (Donn ex Willd.) Howell = *Claytonia perfoliata* Donn ex Willd.	Montiaceae	Miner' Lettuce, Winter Purslane, Cuban Spinach	Roots are edible raw or boiled	Harrington (1974), Larkcom (1984), and Facciola (1990)
Moraea fugax (D. Delaroche) Jacq.	Iridaceae	Uintjie	Bulbous root is eaten roasted, boiled or stewed with milk in southern Africa	Hedrick (1972), Fox et al. (1982), and Facciola (1990)
Moringa oleifera Lam.	Moringaceae	Horse Radish Tree, Drumstick, Zogale (Huasa), La Mu (Chinese)	Root is used as condiment in China. In Nigeria (Kano State, northern), leaves, roots, young pods and seed oil are eaten	Mortimore (1989) and Hu (2005)
Moringa pterygosperma Gaertn. = *Moringa oleifera* Lam.	Moringaceae	Horse Radish Tree, Drumstick, Shekta (Bombay Presidency, Surat district)	India (Bombay Presidency): roots, leaves, flowers and fruits are eaten cooked in water and mixed with salt and chilli peppers	Gammie (1902)
Mucuna glabra (Reinecke) Wilmot-Dear	Fabaceae	Tupe	Brazil (northeast): flour is made from both the seeds and roots. The flour or starch thus obtained is made into a variety of Brazilian foods including *farofa*, in which the meal is sautéed and mixed with bits of meat, crisp fat, chopped egg, etc.; *boijus*, which are small, sweet cakes; and *angus*, which are dumplings, the flour being merely boiled in water	De Castro (1952)

Murdannia graminea (R. Br.) G. Bruckn.	Commelinaceae	Pink Swamp Lily	Bland, fibrous tubers are eaten raw	Cribb and Cribb (1987), Low (1989, 1991), and Harden (1993)
Musa ornata Roxb.	Musaceae	Flowering Banana, Ornamental Banana, Bronze Banana	In India (Deccan), root is eaten	Watt (1908)
Musa paradisiaca L.	Musaceae	It'Ath (Teenek, Yucatan)	In Yucatan, corm is eaten as a famine food by the Huastec Maya	Alcorn (1984)
Musa rosacea Jacq. = *Musa balbisiana* var. *balbisiana*	Musaceae	Mauritius Plantain Tree	In India, rhizomes and shoots are eaten	Gammie (1902)
Musa superba Roxb. = *Ensete superbum* (Roxb.) Cheesman	Musaceae	Dwarf Banana, Red Dwarf Banana; Kardai, Kawdar, Rankele (Bombay Presidency)	Roots of wild plantains are dried and pounded, and the flour is used for making bread	Gammie (1902) and Watt (1908)
Muscari neglectum Guss. ex Ten.	Asparagaceae	Musk Hyacinth, Nutmeg Hyacinth	Bulbs are edible	Hedrick (1972) and Facciola (1990)
Myrrhis odorata Scop.	Arecaceae	Sweet Cicely	Roots are boiled, served with oil and vinegar or candied	Grieve (1971), Hedrick (1972), Morton (1976), Launert (1981), and Facciola (1990)
Narcissus x albus Mill. = *Narcissus x medioluteus* Mill.	Amaryllidaceae	Double Daffodil	France: root is recommended as a famine food, boiled, dried or reduced to a flour and cooked as a porridge	Parmentier (1781) (cited by Freedman 2009)
Nelumbium speciosum Willd.	Nelumbonaceae	Pink Water Lily	India: root and seeds are eaten	Gammie (1902) and Watt (1908)
Nelumbo lutea Pers.	Nelumbonaceae	American Lotus, Water Chinquapin	Large tubers, when baked, are sweet and mealy with a flavour somewhat like a sweet potato	Facciola (1990) and Saunders (1920)
Nelumbo nucifera Gaertn.	Nelumbonaceae	Lotus, Lotus Root	Root is eaten raw or cooked; sliced used in stir-fries, soups and stews; or fried as a garnish or side dish. Sliced pieces can be candied or pickled. Lotus root flour is starch and can be used to make desserts	Burkill (1966), Cribb and Cribb (1987), Facciola (1990), Phillips and Rix (1993), Ong (1996), Hu (2005), Santich et al.(2008), van Wyk (2006), and Codex (2014)
Neowerdermannia vorwerkii Frič	Cactaceae	Achacana	Large root is used as food in Bolivia	Gupta and Kanodia (1968b)
Nephrolepis auriculata (L.) Trimen.	Davalliaceae	Tuber Ladder Fern, Tuberous Sword Fern, Sword	Sweet tuber is eaten as snack	Dai et al. (2003), Cao et al. (2007), and Yun et al. (2009b)
Nephrolepis cordifolia (L.) C. Presl	Davalliaceae	Tuber Ladder Fern, Erect Sword Fern, Qiu Jue (Chinese)	China: tuber is used fresh or dried for preparing a broth with chicken or pork	Hu (2005)

(continued)

Table 1 (continued)

Nervilia fordii (Hance) Schltr.	Orchidaceae	Taro Orchid, Qing Tian Kui (Chinese)	Whole plant plus rhizome are used for tea or cooked with pork in broth	Hu (2005)
Nothoscordum andicola Kunth	Amaryllidaceae	False Garlic, Chullkus (Quechua)	Peru (Vilcanota Valley, hills of Canchis): bulbs are boiled, reported to have a 'garlicky' taste and liked for its flavour	Gade (1975)
Nuphar advena R. Br.	Nymphaeaceae	Common Spatterdock	Rootstock is eaten raw, roasted or cooked with meat	Uphof (1968), Hedrick (1972), and Facciola (1990)
Nuphar luteum Sibth. & Sm.	Nymphaeaceae	Yellow Water Lily	Rootstock is boiled as vegetable	Hedrick (1972), Fernald et al. (1958), and Facciola (1990)
Nuphar polysepala Engelm. = *Nuphar lutea* subsp. *polysepala* (Engelm.) E.O. Beal.	Nymphaeaceae	Cow Lily, Spatterdock, Pond Collard	Rich starchy rhizome is used as survival food, after boiling, roasting or baked and skin is removed	Schofield (2003)
Nuphar pumilum (Timm.) DC.	Nymphaeaceae	Yellow Pond Lily, Ping Peng Cao (Chinese)	Young tender rhizomes are used as potherb in Yunnan and Hubei	Hu (2005)
Nuytsia floribunda R. Br.	Loranthaceae	Christmas Tree	Roots are eaten by aborigines, roasted and made into cakes	Low (1989)
Nymphaea lotus L.	Nymphaeaceae	Egyptian Lotus, White Lotus	Tubers are edible	Tanaka (1976), Kunkel (1984), and Facciola (1990)
Nymphaea stellata Willd. = *Nymphaea nouchali* Burm.f.	Nymphaeaceae	Blue Lotus of India	Rhizomes are eaten raw or roasted	Uphof (1968), Hedrick (1972), Tanaka (1976), and Facciola (1990)
Nymphaea alba L.	Nymphaeaceae	White Lotus, European White Waterlily	In France, root is recommended as a famine food after cooking in water and being flavoured	Parmentier (1781) (cited by Freedman 2009)
Nymphaea caerulea Savigny = *Nymphaea nouchali* var. *caerulea* (Savigny) Verdc.	Nymphaeaceae	Blue Lotus of Egypt, Blue Water Lily	Starchy tubers are eaten boiled or roasted	Tanaka (1976), Fox et al. (1982), and Facciola (1990)
Nymphaea edulis DC.	Nymphaeaceae	Red Water Lily; Shunguneer Pushpum (Tamil); Koteka, Kalharamu (Telugu)	In India (Madras Presidency), roots and seeds are cooked and eaten	Shortt (1887–1888)
Nymphaea gigantea Hook.	Nymphaeaceae	Giant Water Lily	Tuberous rootstock is eaten	Cribb and Cribb (1987)
Nymphaea lotus var. *pubescens* (Willd) Hook.f. & Thomson = *Nymphaea pubescens* Willd.	Nymphaeaceae	Red Water Lily	Root is eaten baked or boiled with salt added	Paton and Dunlop (1904)

Nymphaea lotus L.	Nymphaeaceae	Egyptian Lotus, White Lotus, Bado (Hausa), Dambi (Kanuri)	In upper Guinea, Africa, root is used as a famine food, being either roasted in ashes or dried before being ground into flour. In Nigeria (Kano State, northern): rhizome and seeds are eaten. In India (Bombay Presidency), roots and seeds are eaten	Gammie (1902), Watt (1908), Irvine (1952), Uphof (1968), Hedrick (1972), Tanaka (1976), Pongpangan and Poobrasert (1985), Mortimore (1989), and Facciola (1990)
Nymphaea nouchali Burm.f.	Nymphaeaceae	Boga Bhet, Seluk (Assamese)	Rhizomes/roots are eaten raw or cooked as vegetable in Assam	Van den Bergh (1994) and Patiri and Borah (2007)
Nymphaea odorata Aiton	Nymphaeaceae	Fragrant Water Lily	Tubers are edible	Tanaka (1976), Kunkel (1984), and Facciola (1990)
Nymphaea rubra Roxb. ex Andrews	Nymphaeaceae	Ronga Bhet, Mokua, Seluk (Assamese)	As above	Patiri and Borah (2007)
Nymphaea spp.	Nymphaeaceae	Waterlilies	Fibrous tubers are edible	Cribb and Cribb (1987) and Low (1989)
Nymphaea stellata Willd. = *Nymphaea nouchali* Burm.f.	Nymphaeaceae	Izibo (Zulu)	In Zululand (Ubombo district), tuber is boiled and eaten. In India, roots and seeds are eaten	Hely-Hutchinson (1898), Gammie (1902), Watt (1908), and Uphof (1968)
Nymphaea tetragona Georgi	Nymphaeaceae	Four-Angled Water Lily, Shui Lian (Chinese)	Rhizomes are used as food in northwestern China	Hu (2005)
Nymphaea tuberosa Paine = *Nymphaea odorata* subsp. *tuberosa* (Paine) Wiersema & Hellq.	Nymphaeaceae	Tuberous Water Lily, White Water Lily	Tubers are occasionally eaten	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Nymphoides crenata (F. Muell.) Kuntze	Menyanthaceae	Wavy Marshwort	Tubers are eaten	Cribb and Cribb (1987) and Harden (1992)
Nymphoides geminata (R. Br.) Kuntze	Menyanthaceae	Entire Marshwort	Tubers are eaten by aborigines	Cribb and Cribb (1987) and Harden (1992)
Oenanthe pimpinelloides L.	Apiaceae	Meadow Parsley	Roots are prized as food in certain areas in Europe	Grieve (1971), Hedrick (1972), and Facciola (1990)
Oenanthe apiifolia Brot.	Apiaceae	Water Dropwort	In France, starch of root is recommended for extending bread flour, after removal of toxic element	Parmentier (1781) (cited by Freedman 2009)
Oenanthe javanica (Blume) DC.	Apiaceae	Water Dropwort, Seri	Roots are esteemed for cooking	Tanaka (1976) and Facciola (1990)
Oenanthe sarmentosa C. Presl. ex DC.	Apiaceae	Pacific Dropwort, Water Parsley	Black tubers are esteemed by native Indians, when boiled has a parsley flavour	Yanovsky (1936), Hedrick (1972), and Facciola (1990)

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Table 1 (continued)

Oenothera biennis L.	Onagraceae	Evening Primrose, German Rampion	Roots are boiled, fried, scalloped, au gratin, or added to stews and soups	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Oenothera erythrosepala Borbás = *Oenothera glazioviana* Micheli	Onagraceae	Large Evening Primrose	Edible roots	Cribb and Cribb (1987)
Oenothera hookeri Torr. & A. Gray = *Oenothera elata* Kunth	Onagraceae	Hooker's Evening Primrose	Roots are cooked like parsnip	Harrington (1974) and Facciola (1990)
Onoclea sensibilis L.	Woodsiaceae	Sensitive Fern	Rootstock is used as food	Yanovsky (1936) and Facciola (1990)
Ondinea purpurea Hartog	Nymphaeaceae	NF	Corms are eaten by Australian aborigines	Les (2003)
Ophiopogon japonicus (Thunb.) Ker Gawl.	Asparagaceae	Mondo Grass	In China, tubers are eaten	Read (1946)
Orchis mascula (L.) L.	Orchidaceae	Male Orchis, Early Purple Orchid	Dried root is cooked and eaten, also a source of salep, bassorine or sahlab, a fine, yellowish-white powder used as food	Watt (1908), Uphof (1968), Hedrick (1972), and Facciola (1990)
Orchis militaria L.	Orchidaceae	Military Orchid	In France, bulbs are recommended as a source of edible starch (salep), after processing and drying	Parmentier (1781) (cited by Freedman 2009) Facciola (1990)
Orchis morio L. = *Anacamptis morio* (L.) R.M. Bateman, Pridgeon & M.W. Chase	Orchidaceae	Green-Winged Orchid, Gandergoose	As for *O. mascula*	Grieve (1971), Hedrick (1972), and Facciola (1990)
Orchis palmata Gilib. = *Dactylorhiza incarnata* subsp. *incarnata*	Orchidaceae	Palm Orchid	In France, bulbs are recommended as a source of edible starch (salep), after processing and drying	Parmentier (1781) (cited by Freedman 2009)
Orchis pyramidalis L. = *Anacamptis pyramidalis* (L.) Rich.	Orchidaceae	Pyramidal Orchid	As above	Parmentier (1781) (cited by Freedman 2009)
Ornithogalum gramineum Sims = *Nothoscordum bivalve* var. *bivalve*	Asparagaceae	False Garlic, Crowpoison	In France, root is recommended as a famine food, boiled in water, roasted or sliced and fried	Parmentier (1781) (cited by Freedman 2009)
Ornithogalum luteum L. = *Gagea lutea* (L.) Ker Gawl.	Asparagaceae	Yellow Star-of-Bethlehem	As above	Parmentier (1781) (cited by Freedman 2009)

Ornithogalum umbellatum L.	Asparagaceae	Star-of-Bethlehem, Dove's Dung, Pigeon's Dung, Bird's Milk	Middle East: when in famine, food bulbs were ground up after numerous boilings, to eliminate the poisonous principles and then mixed with cereal flour to make bread	Calcott (1842), Moldenke (1954), and Facciola (1990)
Orobanche cernua Loefl.	Orobanchaceae	Tarthuth	Roots are roasted and eaten	Facciola (1990)
Orobus tuberosus L. = *Lathyrus linifolius* (Reichard) Bassler	Fabaceae	Tuberous Bitter Vetch	In France, boiled root is eaten as a famine food	Parmentier (1781) (cited by Freedman 2009)
Orontium aquaticum L.	Araceae	Golden Club	Bulbous rootstock is eaten cooked	Saunders (1920)
Orthoceras strictum R. Br.	Orchidaceae	Horned Orchid, Bird's-Mouth Orchid	Tubers are fragrant, starchy and edible	Low (1989) and Harden (1993)
Osmorhiza aristata (Thunb.) Rydb.	Apiaceae	Longstyle Sweetroot, Smooth Sweet Cicely, Yabu Ninjin	In China, roots are peeled, washed and eaten raw	Read (1946), Tanaka (1976), and Facciola (1990)
Osmorhiza claytonia (Michx.) C.B. Clarke = *Osmorhiza aristata* var. *aristata*	Apiaceae	Anise, Sweet Cicely	Roots are used for its anise-like flavouring	Yanovsky (1936), Facciola (1990), and Seidemann (2005)
Osmorhiza japonica Sieb. & Zucc.	Apiaceae	Japanese Sweet Cicely	In China, roots are peeled, washed, and eaten raw	Read (1946)
Osmorhiza longistylis (Torr.) DC.	Apiaceae	Aniseroot, Smooth Sweet Cicely, Sweet Myrrh	Tea has anise-like flavour, chewed, used in tea or for flavouring	Tanaka (1976) and Facciola (1990)
Osmorhiza occidentalis (Nutt.) Torr.	Apiaceae	Western Sweetroot, Western Sweet Cicely	Tea has anise-like flavour used for flavouring cookies and other foods	Harrington (1974) and Facciola (1990)
Osmunda japonica Thunb.	Osmundaceae	Japanese Cinnamon Fern, Zenmai (Japanese)	Rhizome starch is used for noodles and liquor	Flores et al. (2003), Freedman (2009), Fox et al. (1982), and Gade (1975)
Oxalis corymbosa DC. = *Oxalis debilis* var. *corymbosa* (DC.) Lourteig	Oxalidaceae	Pink Shamrock	Sweet crisp swollen taproot is eaten	Cribb and Cribb (1987)
Oxalis deppei Lodd. ex Sweet	Oxalidaceae	Orach, Deppei Wood Sorrel	Fleshy root is eaten boiled in Mexico	Fernald et al. (1958) and Facciola (1990)
Oxalis perennans Haw.	Oxalidaceae	Grassland Wood Sorrel	Small taproots are eaten by aborigines	Low (1991)
Oxalis radicosa A. Rich. = *Oxalis corniculata* L.	Oxalidaceae	Dwarf Wood Sorrel	Small taproots eaten by aborigines	Low (1991)
Oxalis sp.	Oxalidaceae	Wood Sorrel	Small taproots are eaten by aborigines	Low (1991)

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Table 1 (continued)

Oxalis stricta L.	Oxalidaceae	Yellow Wood Sorrel	Roots are edible	Yanovsky (1936), Uphof (1968), and Facciola (1990)
Oxalis tuberosa Molina	Oxalidaceae	Oca	Tubers are eaten boiled, roasted or candied, one of the principal food crops of the Indians in the Andes, second to potato; tubers can be eaten unpeeled, raw, in salads, pickled, boiled, fried or in soups and stews, also can be dried in the sun to sweeten up	Facciola (1990), Groen et al. (1996), Flores et al. (2003), van Wyk (2006), and Santich et al. (2008)
Oxalis violacea L. = *Oxalis debilis* var. *corymbosa* (DC.) Lourteig	Oxalidaceae	Violet Wood Sorrel	Roots are edible	Yanovsky (1936) and Facciola (1990)
Pachyrhizus ahipa (Wedd.) Parodi	Fabaceae	Ahipa, Yam Bean	The roots are sweet and crispy; when eaten raw it can be peeled like banana or eaten as snacks or in green and fruit salads or prepared as juice	Popenoe et al. (1989), Sørensen et al. (1997), Hermann and Heller (1997), and Codex (2014)
Pachyrhizus angulatus Rich. ex DC. = *Pachyrhizus erosus* (L.) Urb.	Fabaceae	As below	In India, root is eaten	Watt (1908)
Pachyrhizus erosus (L.) Urban	Fabaceae	Yam Bean, Jicama, Sengkuang, Bangkwaun	Sweetish, subglobose tuberous root is eaten fresh raw as a snack or cooked, stir-fried, stewed and in other dishes	Burkill (1966), Facciola (1990), Sørensen (1996), Sørensen and van Hoof (1966), Santich et al. (2008), van Wyk (2006), and Codex (2014)
Pachyrhizus tuberosus (Lam.) Spreng.	Fabaceae	Amazonian Yam Bean, Jicama, Jactupe	As above	Hedrick (1972) and Sørensen (1996)
Paederia foetida L.	Rubiaceae	Rekang Nemthu	Roots are eaten in Karbi, Assam	Kar and Borthakur (2008)
Paederia stenobotrya Merr.	Rubiaceae	White Paederia	Root is ground with soaked soybean for milk, cooked and given to people with jaundice	Hu (2005)
Paeonia foemina Mill. = *Paeonia officinalis* L.	Paeoniaceae	Peony	In France, starch of root is used as a famine food for extending bread flour, after removing bitter element	Parmentier (1781) (cited by Freedman 2009)
Paeonia lactiflora Pallas	Paeoniaceae	Peony	Root with bark is removed, dried and used to prepare health food	Facciola (1990), Hu (2005), and Lim (2014)
Panax bipinnatifidus Seem.	Araliaceae	Pearl Gisang, Ge Da Qi (Chinese)	As below	Codex (2014)

Panax ginseng C.A. Meyer	Araliaceae	Ginseng, Chinese Ginseng, Korean Ginseng, Asian Ginseng; Ren Shen, Jen Shen (Chinese)	Roots are eaten fresh in same amount like carrot or used in soups, chicken broth, noodles and other meat dishes and health foods by the Chinese in Asia and Koreans	Hu (2005), van Wyk (2006), and Codex (2014)
Panax japonicus (T. Nees) C.A. Mey.	Araliaceae	Japanese Ginseng	As above	Codex (2014)
Panax quinquefolius L.	Araliaceae	American Ginseng	As true ginseng substitute	Facciola (1990), Hu (2005), and Codex (2014)
Panax vietnamensis Ha & Grusshv.	Araliaceae	Vietnamese Ginseng	As above	Codex (2014)
Panax wangianus S.C. Sun	Araliaceae	Sanchi Ginseng; Sanchi, San Qi (Chinese)	As for ginseng and in a special chicken sanchi dish	Hu (2005)
Passiflora quadrangularis L.	Passifloraceae	Giant Granadilla	Roots are baked, roasted and eaten like yams	Uphof (1968), Morton (1976), Facciola (1990), and Lim (2012c)
Pastinaca sativa L.	Apiaceae	Parsnip	Swollen root is eaten after cooking, lends itself to slow cooking such as simmering, slow roasting and braising, goes well in soups and stewed and stock, pairs well with salty foods like cod and bacon. The high sugar content was exploited to produce jams, sweet flour for cakes and even parsnip wine; candied parsnip is a popular snack in North America	Burkill (1966), Facciola (1990), Hu (2005), Santich et al. (2008), van Wyk (2006), Phillips and Rix (1993), and Codex (2014)
Pastinaca sylvestris Mill. = *Pastinaca sativa* L.	Apiaceae	Parsnip	In France, root is eaten as a famine food. The cooked root can be eaten with butter and salt	Parmentier (1781) (cited by Freedman 2009)
Pedicularis carnosa Wall.	Orobanchaceae	Entire Leaf Lousewort, Sam Thapar	Roots are eaten in Meghalaya	Sawian et al. (2007)
Pedicularis kanei Dur. = *Pedicularis lanata* Cham. & Schlecht.	Orobanchaceae	Arctic Lousewort, Fernweed, Bumblebee Plant	Roots are nibbled raw or served boiled, baked or stir-fried, use in soups and stew or candy roots like yam or steam like carrots	Schofield (2003)
Pediomelum cuspidatum (Pursh) Rydb. = *Psoralea cuspidata* Pursh	Fabaceae	Indian Turnip, Largebract Indian Breadroot	As for *P. esculenta*	Yanovsky (1936) and Harrington (1974)

(continued)

Table 1 (continued)

Pediomelum esculentum (Pursh) Rydb. = *Psoralea esculenta* Pursh	Fabaceae	Prairie Turnip, Indian Breadroot, Tipsin, Scurfpea, Timpsula	Tuber is edible, eaten raw or in stews, ground to flour for soups and bread	Yanovsky (1936) and Kaldy et al. (1980)
Pediomelum hypogaeum var. *hypogaeum* (Nutt.) Rydb. = *Psoralea hypogaea* Torr. & A. Gray	Fabaceae	Little Indian Breadroot, Subterranean Indian Breadroot	As above	Yanovsky (1936) and Harrington (1974)
Pediomelum tenuiflorum (Pursh) A.N. Egan	Fabaceae	Slimflower Scurfpea	As above	Yanovsky (1936)
Pediomelum subacaule (Torr. & A. Gray) Rydb.	Fabaceae	Whiterim Scurfpea	As above	Yanovsky (1936)
Pelargonium australe J. Jacq.	Geraniaceae	Native Storksbill, Wild Geranium	Taproot is eaten	Low (1991)
Peltandra alba Raf. = *Peltandra sagittifolia* (Michx.) Morong	Araceae	White Arrow Arum	Fleshy rootstock dried and thoroughly cooked can be eaten	Saunders (1920)
Peltandra virginica (L.) Schott	Araceae	Arrow Arum, Virginia Tuckahoe	As above	Saunders (1920)
Peniocereus greggii (Engelm.) Britton & Rose	Cactaceae	Deerhorn Cactus	Tubers are parboiled, dipped in batter and made into fritters	Hedrick (1972), Kunkel (1984), and Facciola (1990)
Perideridia gairdneri (Hook. & Arn.) Mathias	Apiaceae	Common Yampah, Gardner's Yampah	Roots are edible	Kaldy et al. (1980)
Perideridia sp.	Apiaceae	Yampa, Squawroot, False Caraway	Fleshy root is eaten raw, boiled, baked or preserved for later used	Yanovsky (1936), Hedrick (1972), Harrington (1974), and Facciola (1990)
Petalostemon candidum (Willd.) Michx. = *Dalea candida* Willd.	Fabaceae	White Prairie Clover	Roots are eaten or chewed for the sweet flavour	Yanovsky (1936), Uphof (1968), and Facciola (1990)
Petasites frigidus (L.) Fr.	Asteraceae	Sweet Coltsfoot	Roasted roots are eaten	Uphof (1968), Kunkel (1984), Facciola (1990), and Schofield (2003)
Petroselinum crispum (Mill.) Nyman ex A.W. Hill. Radicosum Group	Apiaceae	Turnip-Rooted Parsley, Hamburg Parsley	Swollen taproot cultivars are eaten as aromatic vegetable, slow cooking methods, roasted or simmered as vegetables, added to stock, soups, stews and braised dishes	Facciola (1990), Phillips and Rix (1993), Ipor and Oyen (1999), Santich et al. (2008), and Codex (2014)
Peucedanum ambiguum (Nutt.) Nutt. ex Torr. & A. Gray = *Eulophus ambiguous* Nutt.	Apiaceae	Biscuit-Root	Tubers has a celery flavour and may be consumed raw	Saunders (1920)

Peucedanum canbyi J.M. Coult. & Rose = *Cogswellia canbyi* M.E. Jones	Apiaceae	Biscuit-Root, Chuklusa (Spokane Indians)	Tubers may be consumed raw or mixed with water, flattened into cakes and dried in the sun or baked	Saunders (1920)
Peucedanum cous S. Watson = *Cogswellia cous* M.E. Jones	Apiaceae	Cow-As (Indians)	Tubers have a celery flavour and may be consumed raw	Saunders (1920)
Peucedanum eurycarpum J.M. Coult. & Rose	Apiaceae	Biscuit-Root	As above	Saunders (1920)
Peucedanum geyeri S. Watson = *Cogswellia geyeri* M.E. Jones.	Apiaceae	Biscuit-Root	As above	Saunders (1920)
Phaseolus adenanthus G. Mey. = *Vigna adenantha* (G. Mey.) Marechal & al.	Fabaceae	Adzuki Bean, Moth Bean, Wild Pea Adzuki Bean, Moth Bean, Wild Pea	In India, root is eaten cooked	Watt (1908), Hedrick (1972), and Facciola (1990)
Phaseolus coccineus L.	Fabaceae	Runner Bean, Scarlet Runner Bean, Dutch Runner Bean	Starchy tuberous root is eaten	Popenoe et al. (1989) and Facciola (1990)
Phaseolus rostratus Wall. = *Vigna adenantha* (G. Mey.) Marechal & al.	Fabaceae	Karalsona (Tamil); Karalasana, Karu Alachandra (Telugu)	In India (Madras Presidency), tuberous roots are eaten cooked	Shott (1887–1888) (cited by Freedman 2009)
Phlomis tuberosa L.	Lamiaceae	Tuberous Jerusalem Sage, Bodmon Sok	Roots are eaten by the Kalmucks in Eurasia	Hedrick (1972)
Phragmites australis (Cav.) Trin. ex Steud.	Poaceae	Common Reed Grass	Rhizomes are cooked like potatoes	Tanaka (1976), Fernald et al. (1958), and Facciola (1990)
Phrynium capitatum Willd. = *Phrynium pubinerve* Blume	Marantaceae	Packing Leaf	Root tuber is eaten in Meghalaya	Sawian et al. (2007)
Phyteuma orbiculare L.	Campanulaceae	Round-Headed Rampion	Fleshy roots are consumed in salads and cooked as vegetables in Europe	Uphof (1968) and Facciola (1990)
Phyteuma spicatum L.	Campanulaceae	Spiked Rampion	As above	Hedrick (1972) and Facciola (1990)
Phytolacca acinosa Roxb.	Phytolaccaceae	Poke Root, Indian Pokeberry	In China, root is eaten after boiling and a few changes with water	Darlington and Janaki Ammal (1945) and Read (1946)
Phytolacca acinosa var. *esculenta* Maxim.	Phytolaccaceae	Yama Gobo (Japanese)	Roots are edible	Tanaka (1976) and Facciola (1990)
Picris echioides L. = *Helminthotheca echioides* (L.) Holub	Asteraceae	Bristly Ox-Tongue	In France, root is eaten as a famine food	Parmentier (1781) (cited by Freedman 2009)

(continued)

Table 1 (continued)

Picris evae Lack	Asteraceae	Native Hawkweed	Slender carroty root baked and eaten by aborigines	Cribb and Cribb (1987) and Harden (1992)
Piper methysticum L.f.	Piperaceae	Kava, Kava-Kava, Awa, Kava Pepper	The root and rhizome (underground stem) of kava are used to prepare beverages, extracts, capsules, tablets and topical solutions. Kava is widely and commonly consumed as a social beverage to establish kinship in the Pacific island communities	McDonald and Jowitt (2000) and NCAM (2006)
Plantago major L.	Plantaginaceae	Common Plantain, Greater Plantain	Roots are edible	Fernald et al. (1958) and Facciola (1990)
Platanthera delavayi Schltr. = *Platanthera mandarinorum* Rchb.f.	Orchidaceae	Mandarin Platanthera, Ji Zhua Shen (Chinese)	Fleshy root is cooked	Hu (2005)
Platycodon grandiflorus (Jacq.) A. DC.	Campanulaceae	Chinese Balloon Flower, Jie Geng (Chinese), Doraji (Korean), Kikyo (Japanese)	Dried root is used for soup or tea	Hu (2005), Read (1946), and Codex (2014)
Plectranthus barbatus Andrews	Lamiaceae	Indian Coleus	Tubers are eaten	Jansen (1996b)
Plectranthus edulis Agnew	Lamiaceae	Gala Potato	Tubers are eaten	Jansen (1996b)
Plectranthus esculentus N.E. Br.	Lamiaceae	Livingstone Potato, Kaffir Potato	Stem tubers are eaten, eaten raw or boiled and eaten as vegetables	Jansen (1996b), Phillips and Rix (1993), van Wyk (2006), and Codex (2014)
Plectranthus madagascariensis (Pers.) Benth.	Lamiaceae	Madagascar Spur Flower	Tubers are eaten in Madagascar	Tanaka (1976) and Facciola (1990)
Plectranthus rotundifolius (Poir.) Spreng.	Lamiaceae	Chinese Potato, Coleus Potato, Hausa Potato	Young aromatic tubers are used in soup and vegetable dishes	Jansen (1996b) and Codex (2014)
Podolepis jaceoides (Sims) Voss	Asteraceae	Showy Podolepis	Thickened roots are eaten	Cribb and Cribb (1987)
Polygala japonica Houtt. = *Polygala sibirica* L.	Polygalaceae	Chinese Senega Root, Yuan Zhi (Chinese)	Root is thoroughly washed and boiled several times before consumption	Read (1946)
Polygala tenuifolia Willd.	Polygalaceae	Chinese Senega	As above	Read (1946)
Polygonatum biflorum (Walter) Elliot	Asparagaceae	Small Solomon's Seal	Rootstock is soaked in lye, parboiled and eaten like potatoes or pickled	Hedrick (1972), Gibbons and Tucker (1979), and Facciola (1990)
Polygonatum falcatum A. Gray	Asparagaceae	Deer Bamboo	China: shoot and root are eaten. Root is steamed and sun-dried nine times must be fully grown when processed; otherwise, it stings the throat	Read (1946)

Polygonatum multiflorum (L.) All.	Asparagaceae	Common Solomon's Seal, David's Harp, Ladder-to-Heaven, Eurasian Solomon's Seal	In China, rhizome is eaten	Read (1946)
Polygonatum odoratum (Mill.) Druce	Asparagaceae	Angular Solomon's Seal, Scented Solomon's Seal, Yu Zhu (Chinese)	Rhizome is parboiled and dried, sliced and dried repeatedly and mixed with other Chinese herbs in a refreshing health beverage, used to make tea in Korea and in traditional medicines	Hu (2005)
Polygonatum officinale Allen = *Polygonatum odoratum* var. *odoratum*	Asparagaceae	Solomon's Seal	In China, leaves and rhizomes are milled and eaten	Read (1946)
Polygonatum sibiricum F. Delaroche	Asparagaceae	Siberian Dogwood, Huang Jing (Chinese)	Rhizome contains starch and sugars used for pastries, is steamed, dried repeatedly with sugar or honey, eaten as candy and used in traditional Chinese medicine	Hu (2005)
Polygonatum vulgare Desf. = *Polygonatum odoratum* var. *odoratum*	Asparagaceae	Solomon's Seal	China (northern): rhizome is eaten	Read (1946)
Polygonum *bistorta* L. = *Persicaria bistorta* (L.) Samp.	Polygonaceae	Bistort, Pink Plumes, Snakeweed	Rhizomes are eaten after roasting or sliced for stir-fries or added to soups and stews	Hedrick (1972), Grieve (1971), Facciola (1990), and Schofield (2003)
Polygonum bistortoides Pursh = *Bistorta bistortoides* (Pursh) Small	Polygonaceae	American Bistort	As above	Yanovsky (1936), Harrington (1974), Launert (1981), and Facciola (1990)
Polygonum multiflorum Thunb. = *Fallopia multiflora* (Thunb.) Haraldson	Polygonaceae	Flowery Knotweed; He Shou Wu, Ye Jiao Teng (Chinese)	China: roots are boiled in changes of water to remove the bitter principle and then eaten. Rhizome is used as famine and health food	Read (1946) and Hu (2005)
Polygonum viviparum L. = *Persicaria vivipara* (L.) Ronse Decr.	Polygonaceae	Alpine Bistort	Rhizomes are eaten after roasting or sliced for stir-fries or added to soups and stews	Harrington (1974), Fernald et al. (1958), Facciola (1990), and Schofield (2003)
Polymnia sonchifolia Poepp. = *Smallanthus sonchifolius* (Poepp.) H. Rob.	Asteraceae	Yacon, Llacon, Strawberry Jicama, Bolivian Sunroot	In yacon-producing countries, products made from yacon root include flour, dehydrated products, slice or chips, juices, purees, sweeteners in the form of syrup or tea with high fructooligosaccharide (FOS)	Popenoe et al. (1989), Facciola (1990), and Hermann and Heller (1997)

(continued)

Table 1 (continued)

Polypodium vulgare L.	Polypodiaceae	Oakfern, Tree-Fern	Norway: roots are used to obtain flour for bread or porridge	Sayce (1953)
Portulaca australis Endl.	Portulacaceae	Portulaca	Tuberous roots are eaten after roasting	Cribb and Cribb (1987)
Portulaca intraterranea J.M. Black.	Portulacaceae	Large Pigweed	Australia: root is edible only when cooked	Irvine (1957)
Portulaca tuberosa Roxb.	Portulacaceae	Safed Musli (Rajasthan)	India (Rajasthan, western): roots are eaten raw	Saxena (1979)
Potamogeton crispus L.	Potamogetonaceae	Curly Pond Weed	China: leaves and roots are eaten	Read (1946)
Potentilla anserina L.	Rosaceae	Silverweed, Jue Ma (Chinese)	Roots add a nutty texture to salads and sandwiches. In China, root tuber is dried, boiled with rice in a tonic soup	Cribb and Cribb (1987), Facciola (1990), Schofield (2003), and Hu (2005)
Potentilla discolor Bunge	Rosaceae	Cinquefoil, Fan Bai Cao (Chinese)	China: root is eaten boiled, or raw roots are eaten in northern China	Read (1946) and Hu (2005)
Potentilla egedii Wormsk.	Rosaceae	Silverweed	Roots add a nutty texture to salads and sandwiches	Schofield (2003)
Pouzolzia tuberosa Wight	Urticaceae	NF	India: tuberous roots are eaten	Watt (1908)
Pouzolzia viminea (Blume) Wedd. = *Pouzolzia sanguinea* var. *sanguinea*	Urticaceae	Lipe (Nepal); Mosilo, Ut-Kra (India)	India (Garhwal Himalayas): bark is dried and powdered and then eaten	Gupta (1962)
Prasophyllum brevilabre (Lindl.) Hook.f.	Orchidaceae	Short-Lipped Leek-Orchid	Tubers are eaten by aborigines	Harden (1993)
Prasophyllum campestre R.J. Bates & D.L. Jones	Orchidaceae	Starry Leek-Orchid, Ben Lomond Leek-Orchid	As above	Harden (1993)
Prasophyllum caudiculum D.L. Jones	Orchidaceae	NF	As above	Harden (1993)
Prasophyllum dossenum R.J. Bates & D.L. Jones	Orchidaceae	Tall Leek-Orchid, Piano Orchid	As above	Harden (1993)
Prasophyllum elatum R. Br.	Orchidaceae	Yellow Leek-Orchid	As above	Harden (1993)
Prasophyllum flavum R. Br.	Orchidaceae	Scented Leek-Orchid, Sweet Leek-Orchid	As above	Harden (1993)
Prasophyllum odoratum R.S. Rogers	Orchidaceae	Broad-Lipped Leek-Orchid	As above	Harden (1993)
Prasophyllum patens R. Br.	Orchidaceae	Marsh Leek-Orchid	As above	Harden (1993)
Prasophyllum rogersii Rupp	Orchidaceae	Summer Leek-Orchid	As above	Harden (1993)
Prasophyllum solstitium D.L. Jones	Orchidaceae	NF	As above	Harden (1993)
Prasophyllum sp.	Orchidaceae	Leek Orchids	As above	Cribb and Cribb (1987)

Pseudostellaria heterophylla (Miq.) Pax	Caryophyllaceae	Prince Ginseng, Tai Zhi Shen (Chinese)	Roots are used for soup	Hu (2005)
Psidium guajava L.	Myrtaceae	Guava	Roots are said to be used in soups	Uphof (1968) and Facciola (1990)
Psophocarpus palustris Desv.	Fabaceae	African Winged Bean	Tuberous root is eaten in some parts of Africa	Dalziel (1955), Uphof (1968), and Facciola (1990)
Psophocarpus tetragonolobus (L.) DC.	Fabaceae	Winged Bean Root, Asparagus Bean Root, Goa Bean Root	Tuberous root is eaten	Hu (2005), Facciola (1990), Khan (1994), Lim (2012b), and Codex (2014)
Psoralea badocana (Blanco) Benth. = *Cullen badocanum* (Blanco) Verdc.	Fabaceae	NF	Roots are eaten roasted	Cribb and Cribb (1987)
Psoralea argophylla Pursh	Fabaceae	Silverleaf Scurf Pea, Silverleaf Indian Breadroot	Root is edible raw or cooked in stews, ground into flour for thick soups and bread	Yanovsky (1936) and Tanaka (1976)
Psoralea canescens Michx.	Fabaceae	Buckroot	As above	Yanovsky (1936), Hedrick (1972), and Tanaka (1976)
Psoralea cuspidata Pursh	Fabaceae	Indian Breadroot, Largebract Indian Breadroot	As above	Tanaka (1976) and Fernald et al. (1958)
Psoralea esculenta Pursh	Fabaceae	Breadroot, Prairie Turnip, Prairie Potato	Fresh tubers may be eaten raw with a dressing of oil, vinegar and salt, or they may be boiled or roasted	Saunders (1920), Yanovsky (1936), Uphof (1968), Hedrick (1972), Kaldy et al. (1980), Facciola (1990), and Groen et al. (1996)
Psoralea hypogaea Torr. & A. Gray	Fabaceae	Small Indian Breadroot	As above	Saunders (1920)
Psoralea tenuiflora Pursh	Fabaceae	Slender Scurfy Pea, Slimflower Scurfpea	Root is edible raw or cooked in stews, ground into flour for thick soups and bread	Yanovsky (1936) and Tanaka (1976)
Pteridium aquilinum (L.) Kuhn	Dennstaedtiaceae	Bracken, Brake or Common Bracken; Okang Oing (Mishing); Jue Fen, Jue Tai Cai (Chinese)	In China, rhizomatous roots are eaten as a famine food in Chaotung, southern Szechuan, on the Yunnan border; starch is also extracted from the rhizomes. In Australia, starchy rhizomes are eaten raw or roasted. In India, rhizomes are eaten sometimes as vegetable by Mishing people	Maiden (1889), Irvine (1957), Watt (1908), Sutton (1974), Hu (2005), and Patiri and Borah (2007)
Pteridium aquilinum L. var. *latiusculum* (Desv.) Underw. ex A. Heller	Dennstaedtiaceae	Eastern Bracken	Rhizome starch is used to make noodles, liquor, cakes and other products	Cui (1998), Dai et al. (2003), Cao et al. (2007), and Yun et al. (2009a)

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Table 1 (continued)

Pteridium esculentum (G. Forst.) Nakai	Dennstaedtiaceae	Bracken Fern, Jue (Chinese)	Rhizome is roasted and chewed for the bland white starch	Low (1989)
Pteridium revolutum (Bl.) Nakai	Dennstaedtiaceae	Mao Zhou Jue (Chinese)	Rhizome starch is used to make noodles, liquor, cakes and other products	Cui (1998), Dai et al. (2003), Cao et al. (2007), and Yun et al. (2009a)
Pterostylis abrupta D.L. Jones	Orchidaceae	Abrupt Greenhood, Drooping Greenhood	Tubers are edible	Harden (1993)
Pterostylis alata (Labill.) Rchb.f.	Orchidaceae		Tubers are edible	Harden (1993)
Pterostylis bicolor M.A. Clem. & D.L. Jones	Orchidaceae	Two-Colour Greenhood	Tubers are edible	Harden (1993)
Pterostylis boormanii Rupp	Orchidaceae	Boorman's Ruddyhood	Tubers are edible	Harden (1993)
Pterostylis chaetophora M.A. Clem. & D.L. Jones	Orchidaceae	Hair-Lip Ruddyhood	Tubers are edible	Harden (1993)
Pterostylis coccina Fitzg.	Orchidaceae	Alpen Greenhood	Tubers are edible	Harden (1993)
Pterostylis curta R. Br.	Orchidaceae	Blunt Greenhood	Tubers are edible	Harden (1993)
Pterostylis cycnocephala Fitzg.	Orchidaceae	Swan Greenhood	Tubers are edible	Harden (1993)
Pterostylis daintreana F. Muell. ex Benth.	Orchidaceae	Daintree's Green Hood	Tubers are edible	Harden (1993)
Pterostylis decurva R.S. Rogers	Orchidaceae	Summer Greenhood	Tubers are edible	Harden (1993)
Pterostylis fischii Nicholls	Orchidaceae	Fisch's Greenhood	Tubers are edible	Harden (1993)
Pterostylis hamata Blackmore & Clemesha	Orchidaceae	Hooked Greenhood	Tubers are edible	Harden (1993)
Pterostylis hildae Nicholls	Orchidaceae	Rainforest Greenhood	Tubers are edible	Harden (1993)
Pterostylis laxa Blackmore	Orchidaceae	Antelope Greenhood	Tubers are edible	Harden (1993)
Pterostylis longicurva Rupp	Orchidaceae	Long-Tongued Greenhood	Tubers are edible	Harden (1993)
Pterostylis longifolia R. Br.	Orchidaceae	Tall Greenhood	Tubers are edible, watery and s weetish	Low (1989) and Harden (1993)
Pterostylis longipetala Rupp	Orchidaceae	Curved Greenhood	Tubers are edible	Harden (1993)
Pterostylis mutica R. Br.	Orchidaceae	Midget Greenhood	Tubers are edible	Harden (1993)
Pterostylis nutans R. Br.	Orchidaceae	Nodding Greenhood	Tubers are watery bitter when eaten	Low (1989, 1991)
Pterostylis obtusa R. Br.	Orchidaceae	Jug-Lip Greenhood	Tubers are edible	Harden (1993)
Pterostylis parviflora R. Br.	Orchidaceae	Tiny Greenhood, Jug Orchid, Green Snail Orchid	Tubers are edible	Harden (1993)
Pterostylis pedunculata R. Br.	Orchidaceae	Maroonhood	Tubers are edible	Harden (1993)

Pterostylis praetermissa M.A. Clem. & D.L. Jones	Orchidaceae	Greenhood	Tubers are edible	Harden (1993)
Pterostylis reflexa R. Br.	Orchidaceae	Small Autumn Greenhood	Tubers are edible	Harden (1993)
Pterostylis setifera M.A. Clem., Matthias, & D.L. Jones	Orchidaceae	Bristly Greenhood	Tubers are edible	Harden (1993)
Pterostylis truncata Fitzg.	Orchidaceae	Little Dumpies, Sausage Greenhood	Tubers are edible	Harden (1993)
Pterostylis woollsii Fitzg.	Orchidaceae	Long-Tailed Greenhood, Chinaman Greenhood	Tubers are edible	Harden (1993)
Pterostylis spp.	Orchidaceae	Greenhood	Tubers are eaten by aborigines	Cribb and Cribb (1987)
Pueraria lobata (Willd.) Ohwi = *Pueraria montana* var. *lobata* (Willd.) Sanjappa & Pradeep	Fabaceae	Chik, Kudzu, Pueraria	Tubers are edible; starch from tubers is used for sauces, porridges, jelly puddings, confectionary and beverages in China, Japan and Papua New Guinea, elsewhere used as famine food. Roots are cooked with Chinese dates, sliced yams for a soup	Facciola (1990), Phillips and Rix (1993), Groen et al. (1996), Hu (2005), Walter and Lebot (2007), and Codex (2014)
Pueraria lobata (Willd.) Ohwi var. *lobata* = *Pueraria phaseoloides* var. *phaseoloides* (Roxb.) Benth.	Fabaceae	Kudzu, Japanese Arrowroot	As above	Groen et al. (1996)
Pueraria lobata (Willd.) Ohwi var. *thomsonii* (Benth.) van der Maesen = *Pueraria montana* var. *chinensis* (Ohwi) Sanjappa & Pradeep	Fabaceae	Kudzu, Thomson Kudzu	Tubers are edible	Groen et al. (1996)
Pueraria lobata (Willd.) Ohwi var. *montana* (Lour.) van der Maesen = *Pueraria montana* var. *montana* (Lour.) Merr.	Fabaceae	Kudzu, Taiwan Kudzu	Tubers are edible	Groen et al. (1996)
Pueraria edulis Pamp.	Fabaceae	Edible Kudzu, Ge Gen Fen (Chinese)	Starch from enlarged root is extracted for noodles	Hu (2005)
Pueraria hirsuta Kurz = *Pueraria stricta* Kurz	Fabaceae	Cudzú-Tropical (Portuguese, Brazil)	China: root is steamed and eaten. Japan: processed into flour during the period of scarcity immediately following World War II	Read (1946) and Uphof (1968)
Pueraria montana (Lour.) Merr.	Fabaceae	Ge Ma Mu (Chinese)	Starch is obtained from roots	Hu (2005)

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Table 1 (continued)

Pueraria phaseoloides (Roxb.) Benth.	Fabaceae	Pani Alu (Assamese)	Tuber is fleshy and tasty; it is often eaten raw	Facciola (1990) and Patiri and Borah (2007)
Pueraria thomsonii Benth. = *Pueraria montana* var. *chinensis* (Ohwi) Sanjappa & Pradeep	Fabaceae	Sweet Kudzu; Pani Alu (Assamese); Gang E Teng (Chinese)	Roots sliced used in soup with pork chops in China. In Assam, tuberous roots are eaten cooked	Hu (2005) and Patiri and Borah (2007)
Pueraria thunbergiana (Siebold & Zucc.) Benth. = *Pueraria montana* var. *lobata* (Willd.) Sanjappa & Pradeep	Fabaceae	Kudzu	Fleshy tuber eaten	Read (1946)
Pueraria tuberosa (Willd.) DC.	Fabaceae	Indian Kudzu, Nepalese Kudzu; Urahi Alu, Pani Alu (Assamese); Bilai-Kand, Biralu, Birali Panwa, Sural (Kumaon region, western Himalayas)	Tuberous roots are eaten	Bhargava (1960), Gupta (1962), and Patiri and Borah (2007)
Ranunculus ficaria L. = *Ficaria vederna* Huds.	Ranunculaceae	Pilewort, Lesser Celandine	Roots are cooked and served with meat	Uphof (1968), Launert (1981), and Facciola (1990)
Raphanus raphanistrum subsp. *maritimus* (Sm.) Thell. = *Raphanus raphanistrum* subsp. *landra* (Moretti ex DC.) Bonnier & Layens	Brassicaceae	Sea Radish, Spanish Radish	Taproot is eaten as potherb	Hedrick (1972) and Facciola (1990)
Raphanus sativus L. var. *longipinnatus* L.H. Bailey = *Raphanus raphanistrum* subsp. *sativus* (L.) Domin	Brassicaceae	Japanese Radish	As below	Codex (2014)
Rapahnus sativus Caudatus Group	Brassicaceae	Rat Tail Radish, Monkey Tail Radish	As below	Burkill (1966), Tanaka (1976), and Facciola (1990)
Raphanus sativus Longipinnatus Group	Brassicaceae	Oriental Radish, Lobak, Daikon	As below	Facciola (1990) and van Wyk (2006)
Raphanus sativus cv. group Chinese radish			As below	Piluek and Beltran (1994)
Raphanus sativus cv. small radish group	Brassicaceae		As below	Piluek and Beltran (1994) and van Wyk (2006)
Raphanus sativus L. = *Raphanus raphanistrum* subsp. *sativus* (L.) Domin	Brassicaceae	Radish, European Radish	Swollen fleshy root is eaten as vegetable fresh or dried or pickled or added to soups, stews, stir-fries	Facciola (1990), Phillips and Rix (1993), Piluek and Beltran (1994), Hu (2005), van Wyk (2006), Walter and Lebot (2007), and Santich et al. (2008)

Raphanus sativus L. var. *niger* (Mill.) J. Kern. = *Raphanus raphanistrum* subsp. *sativus* (L.) Domin	Brassicaceae	Black Radish	Taproot is edible	Codex (2014)
Raphionacme brownii Scott-Elliott	Apocyanaceae	Raphionacme; Rujiya (Hausa); Katakirri (Kanuri)	Nigeria (Kano State, northern): tuber is eaten	Mortimore (1989)
Raphionacme daronii Berhaut = *Raphionacme splendens* subsp. *bingeri* (A. Chev.) Venter	Apocyanaceae	A-Ndekap (Bassari), Gamkbuhrongal (Bedik)	Senegal/Guinea: children among the Bedik eat the root and fruits during famine	Ferry et al. (1974)
Rapunculus esculentus Steud. = *Campanula rotundifolia* L.	Campanulaceae	Common Harebell, Bluebell, Blawort Cuckoo Shoe	Root is recommended as famine food. It can be eaten raw in salads	Parmentier (1781) (cited by Freedman 2009)
Rapunculus spicatus (L.) Mill. = *Phyteuma spicatum* L.	Campanulaceae	Spiked Rampion	In France, root is used as a famine food	Parmentier (1781) (cited by Freedman 2009)
Rehmannia glutinosa (Gaertn.) DC.	Plantaginaceae	Chinese Foxglove, Di Huang (Chinese)	Root is used for bupin in China: the leaves either are boiled or may be powdered and mixed with juice from the root and cooked. The root is steamed and sun-dried nine times	Read (1946) and Hu (2005)
Rehmannia lutea Maxim.	Plantaginaceae	Rehmania	As above	Read (1946)
Reichardia picroides (L.) Roth	Asteraceae	French Scorzonera	Roots are eaten	Hedrick (1972) and Facciola (1990)
Reynoutria japonica Houtt.	Polygonaceae	Japanese Knotweed	Rhizomes are edible	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Rhamnus prinoides L'Hér.	Rhamnaceae	Mofifi Buckthorn	Roots are used in soup	Fox et al. (1982) and Facciola (1990)
Rheum nanum Siev. ex Pall.	Polygonaceae	Small Rhubarb, Ai Da Huang (Chinese)	Starch is obtained from caudex and root is used as food in the steppes in northwestern China, Inner Mongolia and Xinjiang	Hu (2005)
Rhexia virginica L.	Melastomataceae	Meadow Beauty, Deer Grass	Tubers are chopped and added to salads or eaten as nibble	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Rhizophora mangle L.	Rhizophoraceae	American Red Mangrove	Roots are used as emergency food	Tanaka (1976) and Facciola (1990)
Rhodiola rosea L. = *Sedum roseum* (L.) Scop.	Crassulaceae	Roseroot	Roots are boiled, seasoned with butter and served with meat or fish	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)

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Table 1 (continued)

Rhus glabra L.	Anacardiaceae	Smooth Sumac, Scarlet Sumac	Roots are peeled and eaten raw	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Romulea bulbocodium (L.) Sebast. & Mauri	Iridaceae	Rocus-Leaved Romulea, Violet Romulea	Bulbous root is eaten by shepherds in northern Africa	Facciola (1990)
Rosa laevigata Michx.	Rosaceae	Cherokee Rose, Jin-Ying Zhi (Chinese)	Sliced roots are used for health tea	Hu (2005)
Rumex acetosella L.	Polygonaceae	Sheep Sorrel	Roots are edible	Harrington (1974), Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Rhynchosia comosa Baker = *Pseudeminia comosa* (Baker) Verdc.	Fabaceae	L'Indo (Sandawe)	In central Tanzania, roots are chewed for juices	Newman (1975)
Saccharum spontaneum L.	Poaceae	Wild Cane, Wild Sugarcane, Fodder Cane; Khagori (Assamese); Mojora (Mishing)	Young shoots and rhizomes are eaten as sugar cane, sweet in taste	Patiri and Borah (2007)
Sagittaria variabilis Engelm. = *Sagittaria latifolia* Willd.	Alismataceae	Arrowhead, Duck Potato	Roasted or boiled, the corms become soft, palatable and digestible	Saunders (1920)
Sagittaria japonica H. Vilm. = *Sagittaria trifolia* L.	Alismataceae	Arrowhead, Arrow Weed, Swamp Potato	Corms are edible	
Sagittaria latifolia Willd.	Alismataceae	Arrowhead, Duck Potato, Wapato	Corms are eaten boiled, creamed, fried and roasted	Gibbons and Tucker (1979), Fernald et al. (1958), Facciola (1990), and Codex (2014)
Sagittaria rigida Pursh	Alismataceae	Sessile-Fruited Arrowhead	Corms are eaten	Facciola (1990)
Sagittaria sagittifolia L.	Alismataceae	Old World Arrowhead, Swamp Potato, Sagittaria	Corms are cooked and eaten	Tanaka (1976), Facciola (1990), Hu (2005), and Codex (2014)
Sagittaria sinensis Sims = *Sagittaria trifolia* L.	Alismataceae	Chinese Arrowhead, Chee Koo, Kuwai	Roasted or boiled, the corms become soft, palatable and digestible	Saunders (1920), Facciola (1990), and Phillips and Rix (1993)
Sagittaria trifolia L.	Alismataceae	Arrowhead, Arrow Weed, Swamp Potato	Corms are consumed boiled	Harrington (1974), Facciola (1990), and Groen et al. (1996)
Salix daphnoides Vill.	Salicaceae	Arctic Willow	Rhizomes are peeled eaten raw or cooked	Uphof (1968), Gibbons and Tucker (1979), and Facciola (1990)
Sambucus javanica Blume	Adoxaceae	Chinese Elderberry, Chieh-Ku-Ts'ao (Chinese)	Roots are parboiled and eaten	Uphof (1968), Tanaka (1976), and Facciola (1990)
Santalum murrayanum C.A. Gardner	Santalaceae	Bitter Quandong	Bark of roots is roasted	Cribb and Cribb (1987)

Sauromatum guttatum Schott = *Sauromatum venosum* (Dryand. ex Aiton) Kunth	Araceae	Voodoo Lily	India: as for *Dioscorea sativa*	Gammie (1902)
Scabiosa japonica Miq.	Caprifoliaceae	Pincushion Flower	In China, roots are eaten	Read (1946)
Schismatoglottis calyptrata (Roxb.) Zoll. & Morit.	Araceae	Guang Xi Luo Yan (Chinese), Nyampon (Indonesia), Alapayi (Philippines)	Stolons are eaten cooked	Ochse and van den Brink (1980) and Van den Bergh (1994)
Schismatoglottis wallichii Hook.f.	Araceae	Arum	Rhizomes are edible	Groen et al. (1996)
Schoenoplectus litoralis (Schrad.) Palla	Cyperaceae	Daly River Club Rush	Edible roots	Cribb and Cribb (1987)
Scilla chinensis Benth. = *Barnardia japonica* (Thunb.) Schult. & Schult.f.	Asparagaceae	Squill	In China, bulb is eaten after thorough soaking and boiling	Read (1946)
Scilla japonica Baker = *Barnardia japonica* (Thunb.) Schult. & Schult.f.	Asparagaceae	As below	As above	Read (1946)
Scilla scilloides (Lindl.) Druce = *Barnardia japonica* (Thunb.) Schult. & Schult.f.	Asparagaceae	Chinese Jacinth, Chinese Squill; Jin Zao Er (Chinese)	Bulb containing starch and sugars, soaked cooked and eaten during famine times	Hu (2005)
Scirpus americanus Pers. = *Schoenoplectus americanus* (Pers.) Volkart	Cyperaceae	Bulrush	Rootstock is eaten raw, boiled, baked or roasted, also pounded into flour	Schofield (2003)
Scirpus californicus (C.A. Mey.) Steud. = *Schoenoplectus californicus* (C.A. Mey.) Soják	Cyperaceae	California Bulrush, Totora	Rhizomes are peeled, baked and eaten	Facciola (1990)
Scirpus grossus L.f. = *Actinoscirpus grossus* (L.f.) Goetgh. & D.A. Simpson	Cyperaceae	Giant Bulrush, Greater Club-Rush	In India and Kumaon region, western Himalayas, roots are burnt and then ground into flour from which bread is prepared	Paton and Dunlop (1904) and Bhargava (1960)
Scirpus lacustris L. = *Schoenoplectus lacustris* (L.) Palla	Cyperaceae	Tule, Greatbulrush	In China, shoots and roots are eaten. Rootstock can be processed into syrup or flour	Saunders (1920), Read (1946), Uphof (1968), Harrington (1974), Gibbons and Tucker (1979), and Facciola (1990)
Scirpus microcarpus J. Presl & C. Presl	Cyperaceae	Bulrush	Rootstock is eaten raw, boiled, baked or roasted	Schofield (2003)
Scirpus paludosus A. Nelson = *Bolboschoenus maritimus* subsp. *paludosus* (A. Nelson) T. Koyama	Cyperaceae	Alkali Bulrush, Nutgrass	Rhizome is eaten raw or made into flour for bread	Uphof (1968), Fernald et al. (1958), and Facciola (1990)

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Table 1 (continued)

Scirpus subterminalis Torr. = *Schoenoplectus subterminalis* (Torr.) Soják	Cyperaceae	Bulrush	Rootstock is eaten raw, boiled, baked or roasted	Schofield (2003)
Scirpus tuberosus Roxb. (illeg.) = *Eleocharis dulcis* (Burm.f.) Trin. ex Hensch.	Cyperaceae	Chechur (Assamese), Khitro (Bodo)	Root tubers are sweet and eaten fresh especially in Upper Assam, also can be cooked as vegetable with potato and chicken	Patiri and Borah (2007)
Scirpus validus Vahl = *Schoenoplectus tabernaemontani* (C.C. Gmel.) Palla	Cyperaceae	Bulrush, Tule, River Club-Rush	White underground shoots after boiling are of excellent flavour; roots are eaten cooked or preserved in rice bran	Tanaka (1976), Cribb and Cribb (1987), Fernald et al. (1958), Facciola (1990), and Schofield (2003)
Scolymus hispanicus L.	Asteraceae	Golden Thistle	Fleshy roots are eaten boiled, mashed, baked or used as substitute for coffee	Hedrick (1972), Tanaka (1976), Kunkel (1984), and Facciola (1990)
Scolymus maculatus L.	Asteraceae	Spotted Golden Thistle, Spanish Salsify, Spanish Oyster Plant	Roots are boiled and eaten	Hedrick (1972), Kunkel (1984), and Facciola (1990)
Scorzonera glabra Rupr.	Asteraceae	Serpent Root, Ya Cong (Chinese)	Roots are eaten as emergency food in northern China	Hu (2005)
Scorzonera hispanica L.	Asteraceae	Black Salsify, Mock Oyster, Coconut Root	Root is peeled after cooking, usually boiled and served along with other vegetables as a side dish or in salads, or cooked in soups and stews. Battered in flour and make into fritters, roasted roots used as coffee substitute	Facciola (1990), Phillips and Rix (1993), Van den Bergh (1994), van Wyk (2006), Santich et al. (2008), and Codex (2014)
Scorzonera humilis L.	Asteraceae	Viper's Grass	In France, root is used as a famine food	Parmentier (1781) (cited by Freedman 2009)
Scrophularia nodosa L.	Scrophulariaceae	Figwort, Woodland Figwort, Common Figwort	In France, starch of root is recommended as famine food for extending bread flour, after removal of bitter element	Parmentier (1781) (cited by Freedman 2009)
Sechium edule (Jacq.) Swartz	Cucurbitaceae	Chayote, Vegetable Pear	Roots are eaten boiled, baked, fried or candied in syrup	Facciola (1990) and Codex (2014)
Silybum marianum (L.) Gaertn.	Asteraceae	Milk Thistle	Roots are eaten raw or cooked	Uphof (1968), Grieve (1971), Larkcom (1984), and Facciola (1990)

Sisarum germanorum Schur	Apiaceae	Chervil	In France, root is recommended as a famine food, eaten with milk or broth	Parmentier (1781) (cited by Freedman 2009)
Sison amomum L.	Apiaceae	Bastard Stone Parsley	Roots are edible	Uphof (1968), Hedrick (1972), and Facciola (1990)
Sium cicutifolium Schrenk = *Sium suave* Walter	Apiaceae	Water Parsnip	Roots are used as food by some Indian tribes in North America	Uphof (1968), Fernald et al. (1958), and Facciola (1990)
Sium sisarum L.	Apiaceae	Skirret	Roots are consumed, used fresh in salad or cooked in stews or soups, also boiled and roasted as a vegetable	Facciola (1990), Phillips and Rix (1993), Hu (2005), Santich et al. (2008), and Codex (2014)
Smallanthus sonchifolius (Poepp.) H. Rob.	Asteraceae	Yacon	See *Polymnia sonchifolia*	Popenoe et al. (1989), Facciola (1990), Hermann and Heller (1997), and Codex (2014)
Smilacina racemosa (L.) Desf. = *Maianthemum racemosum* (L.) Link	Asparagaceae	False Solomon's Seal, Treacle Berry	Rootstock is soaked in lye, parboiled and eaten like potatoes or pickled	Hedrick (1972), Fernald et al. (1958), and Facciola (1990)
Smilax china L.	Smilacaceae	China Root, Ma Chia, Thassap, Susni, Reuchu (Assamese)	Roots are edible, eaten in Assam	Tanaka (1976), Facciola (1990), and Medhi and Borthakur (2012)
Smilax macrophylla Roxb. = *Smilax ovalifolia* Roxb. ex D. Don	Smilacaceae	Kumarika; Tamboli (Bombay)	In India, roots and leaves are eaten	Gammie (1902)
Smilax megacarpa A. DC.	Smilacaceae	Akar Kelona (Malaysia)	Red rhizome is edible	Van den Bergh (1994)
Smilax ovalifolia Roxb. ex D. Don	Smilacaceae	Kumarika	Roots are eaten	Watt (1908)
Smilax pseudochina L.	Smilacaceae	China Brier	Starchy, tuberous roots are chopped, pounded and mixed with water to make a nutritious meal, mixed with fine corn flour, and frying in bear grease gives good hotcakes or fritters	Saunders (1920)
Smilax zeylanica L.	Smilacaceae	Kayu China Hutan (Moluccas), Asihe Tuni (Ambon)	Young roots are boiled and eaten during famine	Groen et al. (1996)
Smyrnium olusatrum L.	Apiaceae	Alexanders, Black Lovage	Roots are boiled and served with oil and vinegar or used in soups	Uphof (1968), Hedrick (1972), Larkcom (1984), and Facciola (1990)
Solanum ajanhuiri Juz. & Bukasov	Solanaceae	Ajanhuri	Root tuber is edible	Codex (2014)
Solanum berthaultii Hawkes	Solanaceae	Wild Potato	Tubers are used like the cultivated potato	Gupta and Kanodia (1968b)

(continued)

Table 1 (continued)

Solanum candolleanum Berthault	Solanaceae	Gentil Achochil Chocke	Tubers are used like the cultivated potato	Gupta and Kanodia (1968b)
Solanum curtilobum Juz. & Bukasov	Solanaceae	Ckaisalla, Bitter Potatoes	Root tuber is edible	Arbizu and Tapia (1994)
Solanum demissum Lindl.	Solanaceae	Papa Cimarrona, Papa Del Monte	Tubers are cooked and eaten	Facciola (1990)
Solanum fendleri A. Gray	Solanaceae	Fendler Potato, Wild Potato	In southwestern United States, root tuber is eaten raw or boiled with clay, by Native American Keresan Pueblo groups	Yanovsky (1936), White (1944), Hedrick (1972), Gibbons and Tucker (1979), and Facciola (1990)
Solanum jamesii Torr.	Solanaceae	Colorado Wild Potato	In southwestern United States, tuber is eaten raw or boiled with clay, by Native American Keresan Pueblo group and also eaten by Navajo Indians. Tubers are also baked or ground into flour	Saunders (1920), Yanovsky (1936), White (1944), Harrington (1974), and Facciola (1990)
Solanum paucijugum Bitter	Solanaceae	Sacha Pappa	Root tuber is edible	Facciola (1990)
Solanum tuberosum L. var. *boreale* A. Gray	Solanaceae	Wild Potato	Root tubers are quite edible when cooked and eaten by Navajo and other Indians	Saunders (1920)
Solanum tuberosum L.	Solanaceae	Potato, Irish Potato	Russet or baking potato is best for roasting, frying or baking; all-purpose potatoes are used for soups, stews and mashing; red and newer cultivars are best for boiling, creaming and in cold salads	Facciola (1990), Phillips and Rix (1993), Wagih and Wiersema (1996), Hu (2005), van Wyk (2006), and Santich et al. (2008)
Solanum tuberosum L. subsp. *andigenum* (Juz. & Bukasov) Hawkes	Solanaceae	Andigena	Root tuber is edible	Codex (2014)
Solanum verrucosum Schltdl.	Solanaceae	Papa Morda	Root tuber is edible	Facciola (1990)
Solanum juzepczukii Bukasov	Solanaceae	Bitter Potatoes	Root tuber is edible	Arbizu and Tapia (1994)
Solenostemon rotundifolius (Poir.) J.K. Morton. = *Plectranthus rotundifolius* (Poir.) Spreng.	Lamiaceae	Hausa Potato, Frafra Potato; Tumuku, Tamaka (Hausa)	Nigeria (Kano State, northern): tuber is eaten like potato	Dalziel (1955), Fox et al. (1982), Mortimore (1989), Facciola (1990), and Codex (2014)
Sonchus oleraceus (L.) L.	Asteraceae	Common Sowthistle	Roots are eaten	Grieve (1971), Fox et al. (1982), Cribb and Cribb (1987), and Facciola (1990)

Spathium chinense Lour. = *Saururus chinensis* (Lour.) Baill.	Saururaceae	Chinese Lizard's Tail	India: tubers are boiled and eaten	Watt (1908)
Spathyema foetida (L.) Rafin. = *Symplocarpus foetidus* (L.) Salisb. ex W.P.C. Barton	Araceae	Skunk Cabbage	Native American: rootstock is used as an emergency food, dried or baked, to improve the taste	Yanovsky (1936), Uphof (1968), Usher (1974), and Harris (1995)
Sphaeralcea coccinea (Nutt.) Rydb.	Malvaceae	Globemallow	North America (Arizona): root is eaten by Native American Navajo group	Elmore (1944)
Sphenostylis stenocarpa (A. Rich.) Harms	Fabaceae	Africa Yam Bean	Tuber is eaten raw or cooked like potato	Kay (1973), Popenoe et al. (1989), and Facciola (1990)
Spiranthes sinensis (Pers.) Ames	Orchidaceae	Ladies Tresses, Chinese Spiranthes	Egg-shaped tubers are edible and eaten	Low (1991) and Harden (1993)
Spondias tuberosa Arruda	Anacardiaceae	Brazil Plum, Umbu or Imbu	Brazil (northeast): roots, in the form of aqueous bulbs, are eaten	De Castro (1952)
Spiranthes lancea (Thunb. ex Sw.) Bakh.f. & Steenis = *Herminium lanceum* (Thunb. ex Sw.) Vuijk	Orchidaceae	Pan Long Shen (Chinese), Mukago-Sou (Japanese)	Fleshy root is cooked with chicken or meat	Hu (2005)
Stachys adulterina Hemsl.	Lamiaceae	Hubei Artichoke, Di Can Zi (Chinese)	Root tubers are used as vegetables, cooked or pickled	Hu (2005)
Stachys affinis Bunge	Lamiaceae	Chinese Artichoke, Cao Shi Can (Chinese)	As above	Phillips and Rix (1993), Hu (2005), and Codex (2014)
Stachys chinensis Bunge ex Benth.	Lamiaceae	Hyssopleaf Hedgenettle	Manchuria: rhizome is eaten	Baranov (1967)
Stachys sieboldii Miq.	Lamiaceae	Crosnes, Chinese Artichoke, Japanese Artichoke	Japan: tubers are salted or preserved in plum vinegar	Read (1946), Facciola (1990), Van den Bergh (1996), and Codex (2014)
Stellaria jamesiana Torr. = *Pseudostellaria jamesiana* (Torr.) W.A. Weber & R.L. Hartm.	Caryophyllaceae	Tuber Starwort	Roots are eaten raw or cooked	Harrington (1974)
Stemona australiana (Benth.) C.H. Wright	Stemonaceae	NF	Fleshy subterranean tubers are edible	Cribb and Cribb (1987)
Stemona tuberosa Lour.	Stemonaceae	Wild Asparagus, Sessile Stemona Root, Japanese Stemona Root, Tuber Stemona Root; Bai Bu (Chinese); Thagdi, Barhtlum (Assamese)	Tuberous root is eaten in Assam	Medhi and Borthakur (2012)
Sterculia foetida L.	Malvaceae	Java Olive	Rootstock can be eaten raw	Kunkel (1984), Pongpangan and Poobrasert (1985), and Facciola (1990)

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Table 1 (continued)

Sterculia urens Roxb. = *Kavalama urens* (Roxb.) Raf.	Malvaceae	Indian Gum Tragcanth, Gum Karaya; Kadhai (Bombay)	In Bombay, India, the tender roots are chopped, boiled and mixed with either spices or sugar	Gammie (1902)
Sterculia villosa Roxb.	Malvaceae	Elephant Rope Tree, Udal, Vakenar	Roots are edible	Burkill (1966), Tanaka (1976), and Facciola (1990)
Streptopus amplexifolius (L.) DC.	Asparagaceae	Liver Berry, Clasping-Leaved Twisted Stalk, Wild Cucumber	Roots are sometimes used in salads	Gibbons and Tucker (1979) and Facciola (1990)
Stylochiton lancifolium Kotschy & Peyr.	Araceae	Gwandai (Huasa, Plant); Kinciyar, Ngurra (Kanuri)	In Nigeria (Kano State, northern), leaves and rhizome are eaten after repeated boiling of young leaves and rhizome to detoxify	Mortimore (1989)
Stylochiton warneckii Engl.	Araceae	A-Nyél Ewùrè (Senegal Basari), Tabal (Senegal, Wolof)	Africa (west): the thickened rhizome is repeatedly washed in ashes and lye to leach out toxic saponins and raphides	Irvine (1952), Uphof (1968), and Burkill (1985)
Swertia bimaculata Hook.f. & Thomas ex C.B. Clarke	Gentianaceae	Double-Spotted Swertia, Chinese Chirata	In China, root is eaten	Read (1946)
Symphytum officinale L.	Boraginaceae	Comfrey	Roasted roots are mixed with chicory roots used as coffee substitute	Grieve (1971), Hedrick (1972), and Facciola (1990)
Synantherias sylvatica (Roxb.) Schott = *Amorphophallus sylvaticus* (Roxb.) Kunth	Araceae	Kuttukaranai (Tamil), Vanakanda (Telugu)	Roots are eaten in India	Watt (1908)
Tacca involucrata Schumach. & Thonn. = *Tacca leontopetaloides* (L.) O. Kuntze	Dioscoreaceae	See below	In Nigeria, the Munshi first boils the tuber to remove the toxic element. A coarse flour, called *amara*, is prepared from it	Irvine (1952)
Tacca leontopetaloides (L.) O. Kuntze	Dioscoreaceae	Polynesian Arrowroot, East Indian Arrowroot, Salep	Root tuber is grated, pounded, soaked and baked	Cribb and Cribb (1987), Wightman and Andrews (1989), Low (1989, 1991), Facciola (1990), Jukema and Paisooksantivatana (1966), Hu (2005), and Codex (2014)
Tacca pinnatifida J.R. Forst & G. Forst. = *Tacca leontopetaloides* (L.) O. Kuntze	Dioscoreaceae	See above	Tubers are usually eaten after preparation, bitter when raw	Burkill (1966)
Taraxacum albidum Dahlst.	Asteraceae	White Dandelion	Roots are edible after parboiling	Tanaka (1976) and Facciola (1990)

Taraxacum officinale Webb	Asteraceae	Dandelion Root	Roots are boiled as vegetable or baked, added to soups and stir-fries. Roasted roots afford a hearty coffee-flavoured beverage free of caffeine	Harrington (1974), Cribb and Cribb (1987), Facciola (1990), Phillips and Rix (1993), Van den Bergh (1994), Schofield (2003), and Codex (2014)
Telosma cordata (Burm.f.) Merr.	Apocynaceae	Fragrant Telosma, Tonkin Creeper, Cowslip Creeper, Pakalana Vine	Fleshy roots are made into sweetmeat by the Chinese in Java	Burkill (1966), Tanaka (1976), and Facciola (1990)
Tetrapanax papyrifer (Hook.) K. Koch	Araliaceae	Rice Paper Plant	Roots are edible	Tanaka (1976) and Kunkel (1984)
Thalia geniculata L.	Marantaceae	Swamp Lily	Rhizomes are baked and eaten or made into a kind of arrowroot	Tanaka (1976) and Facciola (1990)
Thelymitra carnea R. Br.	Orchidaceae	Tiny Sun Orchid, Pink Sun Orchid	Root tubers are edible	Harden (1993)
Thelymitra circumsepta Fitzg.	Orchidaceae	Naked Sun Orchid	Root tubers are edible	Harden (1993)
Thelymitra cyanea (Lindl.) Benth.	Orchidaceae	Veined Sun Orchid	Root tubers are edible	Harden (1993)
Thelymitra fragrans D.L. Jones & M.A. Clem.	Orchidaceae	Frahrant Sun Orchid	Root tubers edible	Harden (1993)
Thelymitra ixioides Sw.	Orchidaceae	Spotted Sun Orchid	Root tubers are bland and glutinous	Low (1991)
Thelymitra megacalyptra Fitzg.	Orchidaceae	Scented Sun Orchid	Root tubers are edible	Harden (1993)
Thelymitra nuda R. Br.	Orchidaceae	Plain Sun Orchid	Root tubers are edible	Low (1989) and Harden (1993)
Thelymitra pauciflora R. Br.	Orchidaceae	Slender Sun Orchid	Root tubers are edible	Harden (1993)
Thelymitra spp.	Orchidaceae	Sun Orchids	Root tubers are eaten by aborigines	Cribb and Cribb (1987)
Thilachium africanum Scott-Elliot = *Thilachium panduriforme* (Lam.) Juss.	Capparaceae	Mutungu (Sandawe), Raa-Wa-Mburi (Kikuya), Mtungu (Kamba), Lolmugi (Samburu), Matanuyu (Masai)	In Tanzania (central), roots are boiled and eaten. In Kenya (Mbeere division, Embu district), after the root bark is removed, the cortex is pounded, soaked, strained and boiled for many hours and used as a porridge	Newman (1975), Kabuye (1986), and Riley and Brokensha (1988)
Thysanotus banksii R. Br.	Asparagaceae	Fringed Lily	Roots are eaten by aborigines	Low (1989)
Thysanotus baueri R. Br.	Asparagaceae	Malee Fringe-Lily	Slender tubers are eaten	Low (1989)
Thysanotus exiliflorus F. Muell.	Asparagaceae	Fringed Violet	As above	Low (1991)
Thysanotus patersonii R. Br.	Asparagaceae	Twining Fringe-Lily, Tjungoori	Bittersweet tubers are eaten	Low (1989, 1991) and Harden (1993)

(continued)

Table 1 (continued)

Thysanotus tuberosus R. Br.	Asparagaceae	Common Fringe-Lily, Violet Lily, Fringed Violet	Sugary tubers are eaten as sweet treats	Cribb and Cribb (1987), Low (1989, 1991), and Harden (1993)
Tigridia pavonia (L.f.) DC.	Iridaceae	Common Tigerflower	Roasted starchy corms are used as food by Mazatecs and other Indian tribes in Mexico	Uphof (1968), Williams (1981), and Facciola (1990)
Trachymene glaucifolia Benth.	Apiaceae	Wild Parsnip, Yam	Sweet, juicy taproots are eaten raw or cooked	Cribb and Cribb (1987), Facciola (1990), and Harden (1992)
Trachymene incisa Rudge	Apiaceae	Wild Parsnip, Yam	Sweet, juicy taproots are eaten raw or cooked	Cribb and Cribb (1987), Low (1991), and Harden (1992)
Tragopogon dubius Scop.	Asteraceae	Goat's Beard	Young roots are edible raw or cooked	Fernald et al. (1958), Harrington (1974), and Facciola (1990)
Tragopogon porrifolius L.	Asteraceae	Salsify, Oyster Plant, Vegetable Oyster	Roots are boiled pleasant with seafood flavour. Roots are eaten in Xinjiang	Facciola (1990), Cribb and Cribb (1987), Harden (1992), Phillips and Rix (1993), and Hu (2005)
Tragopogon pratensis L.	Asteraceae	Meadow Salsify, Showy Goat's-Beard, Meadow Goat's-Beard Meadow Salsify, Showy Goat's-Beard, Meadow Goat's-Beard	In France, root is recommended as a famine food	Parmentier (1781) (cited by Freedman 2009) Facciola (1990)
Tribulus solanderi F. Muell.	Zygophyllaceae	NF	Roots are eaten roasted	Cribb and Cribb (1987)
Trichosanthes japonica Regel	Cucurbitaceae	Trichosanthes Root, Ki-Karasu Uri (Japanese)	In China the starchy root is peeled, sliced, soaked in repeated changes of water and then mashed to a pulp which is made into steamed cakes	Read (1946)
Trichosanthes tricuspidata Lour.	Cucurbitaceae	Thowan	Large underground rootstock is roasted or boiled before eating	Cribb and Cribb (1987)
Trichosanthes kirilowii Maxim.	Cucurbitaceae	Trichosanthes Root, Ki-Karasu Uri (Japanese)	As for *T. japonica*	Read (1946)
Trichosanthes multiloba Miq.	Cucurbitaceae	NF	As above	Read (1946)
Trifolium repens L.	Fabaceae	White Clover	Roots are prized by some native groups in North America	Schofield (2003)
Triglochin procera R. Br.	Juncaginaceae	Water Ribbons	Bullet-shaped tubers	Cribb and Cribb (1987) and Low (1989)
Triticum repens L. = *Elymus repens* (L.) Gould	Poaceae	Couch Grass, Twitch, Quack Grass, Quitch Grass, Dog Grass	In Norway, roots are ground into flour	Sayce (1953)

Tropaeolum tuberosum Ruiz & Pavon	Tropaeolaceae	Mashua, Tuberous Nasutium, Anu, Anyu	An ancient food crop from the Andes, tubers are eaten boiled and as vegetable or added to stews	Popenoe et al. (1989), Facciola (1990), Johns (1981), Groen et al. (1996), Flores et al. (2003), and Codex (2014)
Tulipa edulis (Miq.) Baker = *Amana edulis* (Miq.) Honda	Liliaceae	Edible Tulip	Bulbs are eaten	Hu (2005)
Tussilago farfara L.	Asteraceae	Coltsfoot	Rootstock is candied in syrup	Grieve (1971), Fernald et al. (1958), Gibbons and Tucker (1979), and Facciola (1990)
Tylosema esculentum (Burch.) A. Schreib.	Fabaceae	Marama Bean, Gemsbok Bean	Sweet tuber is baked, boiled or roasted	Fox et al. (1982), Popenoe et al. (1989), and Facciola (1990)
Typha angustata Bory & Chaub. = *Typha domingensis* Pers.	Typhaceae	Narrow-Leaved Cumbungi, Bulrush; Googol Bon, Hati Ghah (Assamese)	Rhizome, young shoots and inflorescence are eaten	Patiri and Borah (2007)
Typha angustifolia L.	Typhaceae	Narrow-Leaf Cattail	Rootstock are eaten boiled like potatoes	Facciola (1990)
Typha australis K. Schum. & Thonn.	Typhaceae	Bulrush, Cattail	French Guinea: rhizomes are eaten in times of famine	Irvine (1952)
Typha capensis (Rohrb.) N.E. Br	Typhaceae	Cattail	Rhizome is eaten	Fox et al. (1982), Kunkel (1984), and Facciola (1990)
Typha domingensis Pers.	Typhaceae	Narrow-Leaved Cumbungi, Bulrush	Rhizomes are used to extract flour	Tanaka (1976), Low (1989), Facciola (1990), and Harden (1993)
Typha latifolia L.	Typhaceae	Common Cattail	In China, the root is peeled, sun-dried, ground into flour and made into cakes which are then steamed. It may make a useful mixture with ordinary flours and be substituted for cornstarch in puddings	Read (1946), Saunders (1920), Schofield (2003), and Codex (2014)
Typha laxmannii Lepech.	Typhaceae	Scented Flag	Rhizome is source of meal made into cakes	Hedrick (1972) and Facciola (1990)
Typha muelleri Rohrb. = *Typha orientalis* C. Presl	Typhaceae	Bulrush, Reedmace, Yinbun	In Australia, roots are eaten raw by the Brisbane tribe. Roots are also roasted in a hollow in the ground and eaten hot	Irvine (1957)
Typha orientalis C. Presl	Typhaceae	Broad-Leaved Cumbungi, Bulrush	Roots are edible	Low (1989) and Harden (1993)

(continued)

Table 1 (continued)

Typhonium angustilobum F. Muell.	Araceae	Black Arum Lily, Dead Horse Lily	Tuberous underground stem is roasted and pounded before eating	Cribb and Cribb (1987)
Typhonium brownii Schott	Araceae	Black Arum Lily, Dead Horse Lily	Tuberous underground stem is roasted and pounded before eating	Cribb and Cribb (1987) and Harden (1993)
Typhonium bulbiferum Dalzell	Araceae	NF	Bulb is eaten	Watt (1908)
Typhonium divaricatum Blume = *Typhonium roxburghii* Schott	Araceae	Rodent Tuber	Bulb is eaten	Watt (1908)
Typhonium roxburghii Schott	Araceae	Dwarf Voodoo Lily; Keladi Puyoh, Birah Kecil (Malaysia); Trenggiling Mentik (Javanese); Ileus (Sundanese); Bira Kecil (Moluccas)	Corms are edible after several boilings	Groen et al. (1996)
Typhonium spp.	Araceae	Black Arum Lilies	Tubers	Low (1989)
Typhonium trilobatum (L.) Schott	Araceae	Bengal Arum; Syam Kachu, Sam Ghas, Sam Kochu (Assamese); Mahora (Thai); Keladi Puyuh (Malaysia)	Leaf blade, petiole, tubers and spadix are eaten cooked as vegetable by Bodo and Rajbongshi people; dried sliced corms are eaten in Indochina	Groen et al. (1996) and Patiri and Borah (2007)
Ullucus tuberosus Caldas	Basellaceae	Ulluco, Papa Lis, Ruba	Tubers are ancient food of the Andes. Eaten fresh, boiled in stews, dried and ground into flour and for later consumption	Facciola (1990), Groen et al. (1996), Busch et al. (2000), Flores et al. (2003), and Codex (2014)
Urtica tuberosa Roxb.	Urticaceae	Pilli Dumpa (Telugu)	In India (Madras Presidency), tuberous roots are boiled and eaten	Shott (1887–1888) (cited by Freedman 2009)
Utricularia vulgaris L.	Lentibulariaceae	Water Bladderwort	In China, herb root is eaten	Read (1946)
Uvularia sessilifolia L.	Colchicaceae	Bellwort, Wild Oats	Rootstock is cooked or used in diet drinks	Fernald et al. (1958), Gibbons and Tucker (1979), and Facciola (1990)
Valeriana ciliata Torr. & A. Gray	Caprifoliaceae	Tobacco Root	Roots are baked and eaten or eaten as vegetable, used in soups or made into bread	Fernald et al. (1958) and Facciola (1990)
Valeriana dioica L.	Caprifoliaceae	Marsh Valerian	Roots are boiled before added to soups or ground into flour	Schofield (2003)
Valeriana edulis Nutt.	Caprifoliaceae	Edible Valerian	As above	Schofield (2003)
Valeriana officinalis L.	Caprifoliaceae	Common Valerain	As above	Schofield (2003)
Valeriana sitchensis Bong.	Caprifoliaceae	Sitka Valerian	As above	Schofield (2003)

Vetiveria nigritana (Benth.) Stapf = *Chrysopogon nigritanus* (Benth.) Veldkamp	Poaceae	Black Vetivergrass, Jema (Huasa)	Nigeria (Kano State, northern): roots are eaten	Mortimore (1989)
Vetiveria zizanioides (L.) Nash = *Chrysopogon zizanioides* (L.) Roberty.	Poaceae	Vetiver Grass, Khas-Khas Grass, Akar Wangi (Malay)	Roots are used to prepare sherbets or soft drinks during summer in Northern India. Vetiver oil is used for flavouring syrups, ice cream and food preservation. Khus essence is used in cool drinks, for reducing pungency of chewing tobacco preparations and to provide sweet note to other masticatories Vetiver roots is used domestically in cooking; it is infused in tea and also used in baking	Pareek and Kumar (2013) and Balasankar et al. (2013)
Vigna lanceolata Benth.	Fabaceae	Pencil Yam Maloga Bean	The tuberous roots were used after roasting and are reportedly one of the best vegetables available to the natives	Cribb and Cribb (1987) and Harden (1991)
Vigna luteola (Jacq.) Benth.	Fabaceae	Dalrymple Vigna, Hairypod Cowpea, Deer Pea, Kuanga	Roots are edible	Fox et al. (1982) and Facciola (1990)
Vigna marina (Burm.) Merr.	Fabaceae	Dune Bean	Roots are edible	Cribb and Cribb (1987)
Vigna radiata (L.) R. Wilczek	Fabaceae	Beach Pea, Notched Cowpea	As above	Cribb and Cribb (1987)
Vigna vexillata (L.) A. Rich.	Fabaceae	Wild Cowpea; Chaoli, Halgia (Bombay)	In India (Bombay Presidency), tubers are eaten. In West Africa, the rootstock is eaten. In Australia (North Queensland), roots are roasted and eaten	Gammie (1902), Irvine (1952, 1957), Cribb and Cribb (1987), and Facciola (1990)
Viola japonica Langsd. ex DC.	Violaceae	Ko-Sumire (Japanese)	Roots are chopped and minced with yam starch to make a mucilaginous soup	Tanaka (1976) and Facciola (1990)
Wahlenbergia agrestis (Wall.) DC. = *Wahlenbergia marginata* (Thunb.) A. DC.	Campanulaceae	Southern Rockbell	In China, roots are eaten	Read (1946)
Wahlenbergia gracilis (G. Forst.) A. DC.	Campanulaceae	Sprawling Bluebell, Australian Bluebell	As above	Read (1946)

(continued)

Table 1 (continued)

Wahlenbergia marginata (Thunb.) A. DC.	Campanulaceae	Blue Flower Shen, Southern Rockbell, Lan Hua Shen (Chinese)	China: roots are eaten. Fleshy root is cooked with chicken or pork for postpartum mothers	Read (1946) and Hu (2005)
Wasabia japonica (Miq.) Matsum. = *Eutrema japonicum* (Miq.) Koidz.	Brassicaceae	Japanese Horseradish, Wasabi	Stem and root are ground to make wasabi sauce, paste or powder and used as a condiment, used with raw fish, tempura, sushi and noodles	Hu (2005) and van Wyk (2006)
Woodwardia japonica (L.f.) Sm.	Blechnaceae	Gou Ji (Chinese)	Rhizome starch is used to make noodles, cakes and liquor	Cui (1998), Dai et al. (2003), Cao et al. (2007), and Yun et al. (2009a, b)
Woodwardia unigemmata (Makino) Nakai	Blechnaceae	Ding Ya Gou Ji (Chinese)	As above	Dai et al. (2003) and Yun et al. (2009b) 39
Wurmbea biglandosa (R. Br.) T.D. Macfarl.	Colchicaceae	Early Nancy	Bitter, unpalatable	Low (1991)
Wurmbea centralis T.D. Macfarl.	Colchicaceae	Early Nancy	Starchy, bitter tuber is eaten	Low (1989, 1991)
Wurmbea dioca (R. Br.) F. Muell.	Colchicaceae	Early Nancy	As above	Low (1989, 1991)
Xanthosoma atrovirens K. Koch & C.D. Bouche = *Xanthosoma sagittifolium* (L.) Schott	Araceae	Yellow Malanga, Yautia Amarilla, Tannia	Tuberous rhizomes are rich in starch – source of commercial starch and a staple food of Dominica	Tanaka (1976), Facciola (1990), and van Wyk (2006)
Xanthosoma maffafa Schott = *Xanthosoma sagittifolium* (L.) Schott	Araceae	As for *Xanthosoma sagittifolium*	Corms are pounded and made into fufu, a starchy food	Dalziel (1955) and Facciola (1990)
Xanthosoma nigrum (Vell.) Mansfield = *Xanthosoma sagittifolium* (L.) Schott	Araceae	Keladi Hitam (Malaysia), Talas Belitung (Indonesia)	Tuberous rhizomes (corms and cormels) are eaten	Jansen and Premchand (1996)
Xanthosoma sagittifolium (L.) Schott	Araceae	Cocoyam, Tannia, New Cocoyam, Yautia, Macabo Cocoya, Elephant Ear; Yautia Dawl Sel Phak, Banai (Assamese)	Tuberous rhizomes (corms and cormels) are eaten in Assam, baked or boiled in Oceania, used like taro to make fufu in Africa. Corms are eaten boiled, baked, pureed in soups, stews and made into chips, pancakes, fritters	Tanaka (1976), Facciola (1990), Phillips and Rix (1993), Jansen and Premchand (1996), van Wyk (2006), Walter and Lebot (2007), Medhi and Borthakur (2012), and Codex (2014)
Xanthosoma violaceum Schott = *Xanthosoma sagittifolium* (L.) Schott	Araceae	Blue Ape, Tannia, Violet-Stemmed Taro; Mani Gisin, Dawlsek Puak (Assamese)	As above	Burkill (1966), Harrington (1974), Facciola (1990), Medhi and Borthakur (2012), and Codex (2014)
Yucca brevifolia Engelm.	Asparagaceae	Joshua Tree	Roots are eaten raw, boiled or roasted	Tanaka (1976) and Facciola (1990)

Zamia floridana A. DC.	Zamiaceae	Coontie, Coontah	A thick, subterranean stem which is exceedingly rich in starch. A nutritious flour made from the stem and root content	Saunders (1920)
Zamia pumila L.	Zamiaceae	Coontie, Compties, Seminole Bread, Comfort Root.	As above	Saunders (1920)
Zehneria indica (Lour.) Keraudren	Cucurbitaceae	Indian Zehneria; Mao Bao Er, Ma Die Er, Ye Shao Gua (Chinese)	Root is boiled with chicken for postpartum mothers to replenish blood	Hu (2005)
Zingiber amaricans Blume = *Zingiber zerumbet* subsp. *zerumbet*	Zingiberaceae	Lampuyang Pahit (Malay)	Young rhizome tip is eaten raw with rich edible	Ochse and van den Brink (1980) and Facciola (1990)
Zingiber aromaticum Valeton = *Zingiber zerumbet* subsp. *zerumbet*	Zingiberaceae	Lampuyang Pahit	Rhizome is edible, fragrant, bitter and pungent	Ochse and van den Brink (1980)
Zingiber cassumunar Roxb. = *Zingiber montanum* (J. König) Link ex A. Dietr.	Zingiberaceae	Cassumunar Ginger; Bengal Gingermoran Ada (Assamese); Bonglai (Malaysia)	In Assam, India and Malaysia, rhizomes are used as condiments; rhizome juice with honey is used for cough problems	Saidin (2000), Seidemann (2005), and Barua et al. (2007)
Zingiber chrysostachys Ridley	Zingiberaceae	Lempui (Malaysia)	Pungent rhizomes used as spice, substitute for *Z. zerumbet*	Jansen (1999) and Seidemann (2005)
Zingiber montanum (J. König) Link ex A. Dietr.	Zingiberaceae	Cassumunar Ginger, Bengal Root, Banglai (Indonesia), Bunglai, Bolai (Malaysia)	Rhizomes used for food flavouring	Wolf et al. (1999)
Zingiber officinale Roscoe	Zingiberaceae	Ginger, Halia (Malaysia)	Underground rhizome is widely used as culinary spice, fresh, whole, slices, diced, crushed or powdered, preserved or pickled. Used to flavour beverages, drinks, ale, etc., used in bakery product and processed food, desserts and cakes, jams, marmalades, and confectionaries	Burkill (1966), Ochse and van den Brink (1980), Cribb and Cribb (1987), Facciola (1990), Sutarno et al (1999), Saidin (2000), Walter and Lebot (2007), van Wyk (2006), and Phillips and Rix (1993)
Zingiber ottensii Valeton	Zingiberaceae	Bunglai Hantu, Panglai Hideung (Indonesia), Lampoyang Hitam, Kunyit Hitam, Berseh Hitam	Pungent rhizome is used as flavouring in traditional Malay cuisine	Jansen (1999) and Saidin (2000)
Zingiber spectabile Griff.	Zingiberaceae	Black Gingerwort, Tepus Tanah, Tepus Halia (Malaysia)	Rhizome is used as flavouring in traditional Malay cuisine	Burkill (1966), Wolf et al. (1999), Saidin (2000), and Seidemann (2005)

(continued)

Table 1 (continued)

Zingiber zerumbet (L.) Roscoe ex Sm.	Zingiberaceae	Wild Ginger, Zerumbet Ginger, Shampoo Ginger; Lampoyang (Malaysia), Phrilang Dung (Assamese)	Rhizome is used as flavouring in traditional Malay cuisine; rhizome is eaten in Karbi, Assam	Ochse and van den Brink (1980), Cribb and Cribb (1987), Facciola (1990), Wolf et al. (1999), Saidin (2000), Seidemann (2005), and Kar and Borthakur (2008)
Zingiber zerumbet (L.) Smith var. *zerumbet*	Zingiberaceae	Lempuyang Gajah, Lempuyang Kapur, Lempuyang Badak (Indonesia)	Rhizome is used as flavouring in traditional Malay cuisine	Wolf et al. (1999)
Zingiber zerumbet (L.) Smith var. *amaricans* Blume	Zingiberaceae	Lampuyang Pahit, Lempuyang Pait, Lempuyang Emprit (Indonesia), Hui Dam (Thai)	As above	Wolf et al. (1999)
Zingiber zerumbet (L.) Smith var. *aromaticum* (Valeton) Theilade	Zingiberaceae	Lampuyang Wangi, Lempuyang Wangi (Indonesia), Lampoyang, Lempoyang, Tepus (Malaysia)	As above	Wolf et al. (1999)
Zizaniopsis miliacea (Michx.) Döll & Asch.	Poaceae	Water Millet, Southern Wild Rice	Young rhizome is cut into pieces, cooked and served with butter	Gibbons and Tucker (1979), Fernald et al. (1958), and Facciola (1990)
Zygotritonia crocea Stapf = *Zygotritonia bongensis* (Pax) Mildbr.	Iridaceae	Baka (Yoruba, Nigeria)	In French Guinea, corms and fruits are eaten during times of famine	Irvine (1952)

NF = Not Found

fingerroot (*Boesenbergia rotunda*) and arrowroot (*Maranta arundinacea*).

A stem tuber is a modified plant storage organ that is formed from thickened rhizome or stolon. The tops or sides of the tuber produce shoots that grow into typical stems and leaves and the undersides produce roots. The stem tuber has all the parts of a normal stem, including nodes (eyes) and internodes. A stem tuber may start off as an enlargement of the hypocotyls of the seedling and may include the epicotyl or upper section of the root as is in the case of maca (*Lepidium meyenii*). More commonly as in *Plectranthus esculentus* in the Lamiaceae family, numerous tubers are formed on short stolons that arise from the base of the stem, or as in potatoes tubers are formed as enlarged stolons thickened and enlarged into storage organs. In some *Cyperus* species, e.g. tigernut or chufa (*C. esculentus*), the stolons end with the growth of tubers that can give rise to new plants. Other striking examples of plants with stem tubers include hog potato or groundnut (*Apios americana*), Jerusalem artichoke or sunchoke (*Helianthus tuberosus*), earthnut pea (*Lathyrus tuberosus*), oca or New Zealand yam (*Oxalis tuberosa*), Chinese artichoke or crosne (*Stachys affinis*), mashua or añu (*Tropaeolum tuberosum*) and ulluco (*Ullucus tuberosus*). In botany, a stolon is a horizontal modified stem arising from the base of a plant that produces new plants from buds at its tip or nodes and forms adventitious roots at the nodes; it can be creeping above the ground surface or underground. An example of a plant with edible stolon is *Imperata cylindrica*. However, some botanists used the term stolons for stem branches that arise from the base of the stem that creeps above the ground and those that creeps horizontally underground as rhizomes. An example of a plant with swollen, above-ground storage stem is the kohlrabi.

Taproot is the true main root of the plant, and in some species the taproot is modified and fleshy, rich in stored nutrients; they may or may not be fused with the hypocotyl or basal stem tissues and may be napiform, globose, conical, fusiform or cylindrical in shape. Notable examples of plants with edible taproots are *Abelmoschu*s spp., beet (*Beta vulgaris*), rutabaga, turnip, *Bunium persicum*, burdock, carrot, radish and daikon, celeriac, jicama and ahipa (*Pachyrhizus* spp.), parsnips, parsley, skirret (*Sium sisarum*), bush potato (*Vigna lanceolata*), salsify (*Tragopogon porrifolius*), black salsify (*Scorzonera hispanica*), tongkat ali (*Eurycoma longifolia*) and many others. Notable examples of plants with edible root tubers or tuberous roots with enlarged root and lateral roots that function as storage organs, lacking nodes, internodes and adventitious buds include pignut or earthnut (*Conopodium majus*); sweet potato (*Ipomoea batatas*); desert yam (*Ipomoea costata*); cassava or yuca or manioc (*Manihot esculenta*); yams (*Dioscorea* spp.); mauka or chago (*Mirabilis expansa*); breadroot, tipsin or prairie turnip (*Psoralea esculenta*); and yacón (*Smallanthus sonchifolius*).

Bulb is a much reduced underground stem bearing at its apex a growing or floral primordium surrounded by thick, fleshy modified scale leaves or leaf bases that serve as food storage organs during dormancy and enable the plant to survive through adverse periods. The fleshy leaves are arranged in a concentric manner. Bulbs can be tunicate, i.e. with membranous papery covering (scale leaves), or tunic that protects the inner fleshy scale leaves from drying and mechanical injury. Examples of tunicate bulbs are the *Allium* onions, leeks, hyacinth and tulips. In imbricate or non-tunicate bulbs, the fleshy scale leaves are not in concentric rings but are loosely arranged or spreading, overlapping one another at the margin. Such a bulb is not a compact body and not usually covered by a common tunic. Examples are the garlic (*Allium sativum*) and some *Lilium* lilies.

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Sagittaria trifolia

Scientific Name

***Sagittaria trifolia* L.**

Synonyms

Sagittaria chinensis Sims, *Sagittaria doniana* Sweet, *Sagittaria edulis* Schltdl., *Sagittaria hastata* D. Don (illeg.), *Sagittaria hirundinacea* Blume, *Sagittaria japonica* H. Vilm., *Sagittaria leucopetala* (Miq.) Bergmans, *Sagittaria macrophylla* Bunge (illeg.), *Sagittaria obtusa* Thunb. (illeg.), *Sagittaria sagittata* Thunb., *Sagittaria sagittifolia* var. *alismifolia* Makino, *Sagittaria sagittifolia* var. *diversifolia* M. Michel, *Sagittaria sagittifolia* var. *edulis* (Schltdl.) Siebold ex Miq.

Sagittaria sagittifolia var. *leucopetala* Miq., *Sagittaria sagittifolia* subsp. *leucopetala* (Miq.) Hartog, *Sagittaria sagittifolia* var. *longiloba* Turcz., *Sagittaria sagittifolia* f. *sinensis* (Sims) Makino, *Sagittaria sagittifolia* var. *subaequilonga* Regel, *Sagittaria sinensis* Sims, *Sagittaria trifolia* f. *albida* Makino, *Sagittaria trifolia* var. *angustifolia* Kitag., *Sagittaria trifolia* f. *caerulea* Makino, *Sagittaria trifolia* var. *edulis* (Schltdl.) Ohwi ex W.T. Lee, *Sagittaria trifolia* f. *heterophylla* Makino, *Sagittaria trifolia* var. *leucopetala* Miq., *Sagittaria trifolia* subsp. *leucopetala* (Miq.) Q.F. Wang, *Sagittaria trifolia* var. *longiloba* (Turcz.) Kitag., *Sagittaria trifolia* var. *retusa* J.K. Chen, X.Z. Sun & H.Q. Wang, *Sagittaria trifolia* var. *sinensis* (Sims) Makino, *Sagittaria trifolia* f. *subhastata* Makino, *Sagittaria trifolia* f. *suitensis* Makino

Family

Alismataceae

Common Names

Arrowhead, arrow-head, Arrow-Weed, Chinese Arrowhead, Chinese Potato, Duck Potato, Old World Arrowhead, Swamp Potato

Vernacular Names

Arabia: Kewi
Chinese: Kunai, Ci-Gu, T'zu-Ku, Bai-Di-Li, Pai-Di-Li, Jian-Dao-Cao, Chien-Tao-Ts'ao, Jiao Bai, Tzi Koo, Ngah Ku, Ya Ku Ye Ci Gu
Cuba: Malanga China
Czech: Šípatka Střelolistá, Šípatka Střelovitá, Šípatka Vodní
Danish: Almindelig Pilblad, Pilblad
Dutch: Pijlkruid
Eastonia: Jõgi-Kõõlusleht
Esperanto: Akvosago, Sagherbo Granda, Sagitario Granda
Finnish: Pystykeiholehti, Yleinen Keiholehti

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French: Fléchière Commune, Fle D'eau, Flèche D'eau, Fli, Sagittaire À Feuilles En Fleche, Sagittaire De Chine, Sagittaire Nageante
Gaelic: Rinn Saighde
German: Brutblatt, Chinesisches Pfeilkraut, Echtes, Gemeines Pfeilkraut, Gewöhnliches Pfeilkraut, Pfeilkraut, Spitzes Pfeilkraut
Hungarian: Nyílfű
India: Jathipotia (Assamese), Koukha (Bengali), Chotokut, Muya-Muya (Hindi)
Indonesia: Bea-Bea, Eceng Genjer, Kalopak
Italian: Erba Saetta, Erba Saetta Chinese, Sagittaria Commune
Japanese: Kuwai, Konwai Shiro-Guwai, Omodaka
Khmer: Slok Lumpaeng
Korean: Soeguenamul, Soegwinamul
Laotian: Phak Sob
Malaysia: Béa-Béa, Ètjèng, Keladi Ubi, Keladi Chabang (Malay) Tse Koo (Cantonese)
Norwegian: Pilblad
Philippines: Gauai-Gauai (Bisaya), Tikog (Bikol)
Polish: Strzałka Wodna
Portuguese: Erva Frecha Chinesa, Espadana, Sagitária
Russian: Strelolist Trekhlistnistnyi, Strelolist
Slovašcina: Streluša Navadna
Slovencina: Šípovka Vodná
Spanish: Flecha Chinesa, Flecha De Agua, Saeta, Saeta Chinesa, Saeta De Agua
Swedish: Pilblad
Thailand: Kha Khiat, Taokiat, Phakkhangkai
Vietnamese: Rau Mac, Tu Coo, Cu Choc
Welsh: Saethlys, Saethlys Saethffeilaidd

Origin/Distribution

Sagittaria trifolia is widespread from south European Russia to Japan and Malaysia as well as in several provinces of China and is indigenous to Afghanistan; Cambodia; China (Anhui, Beijing, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Nei Mongol, Ningxia, Qinghai, Shaanxi, Shandong, Shanghai, Shanxi, Sichuan, Tianjin, Xinjiang, Yunnan, Zhejiang); Hong Kong; India (Assam); Indonesia (Sulawesi, Sumatera); Iran, Islamic Republic of; Japan; Kazakhstan; Kyrgyzstan; Lao People's Democratic Republic; Macao; Malaysia; Myanmar; Nepal; Philippines; Russian Federation (Amur, Buryatiya, Chita, Khabarovsk, Krasnoyarsk); Taiwan, Province of China; Thailand; Turkmenistan; Uzbekistan; and Vietnam (Zhuang 2011).

Agroecology

Being an aquatic herb, it can be found growing in ponds, lakes, marshes, paddy fields and water channels. It prefers shallow, still or slowly flowing water up to 30–60 cm deep although it will grow in a moist or wet loamy soil in a sunny position. It grows best in warm weather and require at least a 6-month growing season in order to produce a crop and is fairly cold tolerant surviving temperatures down to at least −10 °C, though the top growth is damaged once temperatures fall below zero.

Edible Plant Parts and Uses

The petioles and the starchy corms are cooked and eaten in Manipur and Southeast Asia. In Vietnam young petiole leaf and corms are used for soups (Tanaka and Nguyen 2007). The plant is cultivated in China and Japan for starch-containing corms which have been used in a variety of cooked and fresh dishes for centuries. The corms are eaten on its own after boiling, baking, cooking or roasting. The corms can also be dried and ground into a powder, and the powder can be used as gruel and porridge or be added to cereal flours and used in making bread. Young leaves are eaten as vegetables.

Botany

Aquatic, acaulescent, glabrous perennial herb (Plate 1) with fleshy rootstock giving rise to numerous thick, axillary stolons bearing

Plate 1 Arrowhead plant in situ

Plate 2 Arrowhead leaf close-up

somewhat subglobose corms (Plate 3) (tubers) 3–6 cm by 2–5 cm at the tips. Leaves in a radical rosette, mostly emerged, upright, up to 40 cm long by 15 cm wide, sagittate or somewhat hastate, blade ovate or linear-lanceolate, with acute, basal lobes triangular or linear-lanceolate, often longer than the blade, sharply acute (Plate 2); petiole 60–75 cm long, triangular. Inflorescence an unbranched scapose terminal raceme, 30–50 cm long. Flowers in 2–6 whorls of 3 flowers each, unisexual, 1–2 cm across, white; pedicels 8–15 mm long, staminate flowers above, pistillate ones below; sepals and petals 3, petals white, suborbicular, unguiculate, stamens 20 with yellow anthers. Fruit an oblate head, 1 cm diameter consisting of numerous triangularly obovate achenes 3–5 mm by 1.5–3 mm with laterally bent beak and subcrenate to entire wings.

Plate 3 Arrowhead corms

Nutritive/Medicinal Properties

Proximate food value of the raw corm per 100 g edible portion was reported as energy 107 cal, moisture 70.6 %, protein 5 g, fat 0.3 g, total carbohydrate 22.4 g, fibre 0.9 g, ash 1.7 g, Ca 13 mg, P 165 mg, Fe 2.6 mg, K 729 mg, thiamine 0.16 mg, riboflavin 0.04 mg, niacin 1.4 mg and ascorbic acid 5 mg (Leung et al. 1972). The corm starch contained a high level of amylose (25.6 %) and 53 ppm of organic phosphorus and showed Ca X-ray diffraction pattern (Suzuki et al. 1993). Starch granules were oval, deformed sphere or potato tuber-like with about 15 pm in length on average. The number-average degree of polymerisation and apparent degree of polymerisation and distribution of amylose were 2,840, 7,080, and 570–21,300, respectively. The chain length (ratio of total carbohydrate/non-reducing residue) of amylose and amylopectin were 420 and 20.2, respectively. Arrowhead starch showed a little lower pasting temperature and higher breakdown than sweet potato starch. The retrogradation tendency of the aqueous paste showed also similar to that of sweet potato starch. Sugimoto et al. (2001) found that the amylose content of three cultivars of Chinese arrowhead tuber starches determined by amperometric iodotitrimetry were in a range of 28.2–29.9 % and 26.6–31.3 % by gel permeation chromatography of isoamylase-debranched starches. The starches had unique amylopectin short-chain length

distributions of increased amounts of chains with DP (degree of polymerisation) 6 and 7 and decreased amounts of chains with DP 9 compared with waxy maize amylopectin. The X-ray diffractograms of the starches showed A-type patterns. Zhao et al. (2011) found that as *S. trifolia* corm enlarged to about 90 days, the sugar content increased to 28.05 mg/g (Zhao et al. 2011). Fructose and glucose also increased and then decreased. Total starch, amylose and amylopectin content increased, and changes of amylopectin/amylose ratio were always less than 1.

D-raffinose, D-stachyose, D-verbascose, D-fructose, D-galactose and glucose, asparagine and vitamin B were reported by Li (2008).

From *S. trifolia* tubers, four bioactive diterpene ketones, trifoliones A, B, C and D; two diterpene glucosides, sagittariosides a and b; and a nitroethylphenol glycoside, arabinothalictoside were isolated, together with six known diterpenes: isoabienol, 13-episclareol, *ent*-13-epimanoyl oxide (6-deoxyandalusol), *ent*-19-hydroxy-13-epimanoyl oxide, *ent*-kaur-16-en-19-ol and *ent*-kaur-16-en-19-oic acid (Yoshikawa et al. 1993, 1996). A terpenoid, sandaracopimaric acid was isolated from the methanol extract (Yuan et al. 1993). From the methanol extract of the plant ergosterol peroxide, icariside D_2, thalictoside and 4-nitrophenyl β-D-glucopyranoside were isolated (Kim et al. 1998). Seven new entrosane diterpenoids, sagittines A–G (1–7), together with one new labdane diterpene, 13-epimanoyl oxide-19-*O*-α-L-2′,5′-diacetoxyarabinofuranoside (8), were isolated from the whole plant (Liu et al. 2006). Ten diterpenoids were isolated including new compounds sagittine H, sclareol and 19-β-L-3′-acetoxyarabinofuranosyl- *ent*-kaur-16-ene-19-oate (Liu et al. 2009).

Starch from the corm of *Sagittaria trifolia* L. var. *sinensis* Makino (arrowhead) contained 31.65 % of amylose and 0.0897 mg/g of phosphorus (Chang 1988). It had a gelatinization temperature range of 56.1–61.7–64.9 °C, a mixed type of Brabender viscosity pattern, a one-stage swelling pattern, 99.6 % water binding capacity, low solubility in dimethyl sulfoxide and high α-amylase susceptibility. The amylose was found to be a branched molecule of DP 2,202 and was hydrolyzed 86.6 % with β-amylase. Its amylopectin had an average chain length of 24.5 and was hydrolyzed 65.5 % with β-amylase.

Sagittariol a new diterpene was isolated from *S. sagittifolia* and characterised as labda-7,14-dien-13(*S*),17-diol (Sharma et al. 1975). Later, sagittariol was considered to be 17-hydroxymanool, as it possessed an A-B *cis* clerodane skeleton (Sharma et al. 1984).

Twenty-eight compounds were identified in the essential oil of *Sagittaria trifolia*; the major components were found hexahydrofanesyl acetone (62.3 %), tetramethylhexadecenone (5.8 %), myristaldehyde (4.7 %), *n*-pentadecane (2.9 %) and 2-hexyldecanol (2.9 %) (Zheng et al. 2006). Other minor compounds were n-pentylfuran 0.3 %, *n*-decaldehyde 0.4 %, *n*-tetradecane 0.4 %, isocaryophyllene 0.9 %, longifolene 1.2 %, caryophyllene 0.8 %, *trans*-geranylacetone 0.7 %, methyl pentadecane (2.1 %), β-caryophyllene 0.6 %, dimethylundecenol 1.4 %, *n*-cetane 1.1 %, caryophyllene 0.9 %, tridecyl aldehyde 0.6 %, *n*-heptadecane 1.3 %, tetramethylpentadecane 0.6 %, myristic acid 2.1 %, *n*-octadecane 0.6 %, tetramethyl pentadecanol 0.8 %, 2-hexyl-1-decanol 1.2 %, *n*-nonadecane and phenanthrenol 0.8 %.

Diuretic Activity

The alcoholic extract of S. *sagittifolia* was reported to show diuretic activity (Sharma et al. 1975).

Immunomodulatory Activity

A terpenoid, sandaracopimaric acid isolated from the plant exhibited good immunosuppressive activity (Yaun et al. 1993). Several diterpenes trifoliones A, B, C and D exhibited inhibitory effects on the histamine release from rat mast cells induced by compound 48/80 or calcium ionophore A-23187 (Yoshikawa et al. 1993, 1996).

Antimicrobial Activity

The antimicrobial activity of the essential oil was evaluated against seven microorganisms. Studies showed that *S. trifolia* oil had a significant antimicrobial effect on several microorganisms (Zheng et al. 2006). This antimicrobial activity can partly explain why the oil is used medicinally during childbirth and for skin diseases in Chinese traditional medicine. Another study reported that four ent-rosane diterpenoids, sagittines A–D, isolated from the whole plant, exhibited antibacterial activity against the oral pathogens, *Streptococcus mutans* and *Actinomyces naeslundiis*, with MIC values between 62.5 and 125 μg/mL (Liu et al. 2006). Sagittine E was active against only *A. naeslundiis*, with an MIC value of 62.5 μg/mL. Sagittine H, a new *ent*-rosane glycoside, demonstrated antibacterial activity against *Streptococcus mutans* and *Actinomyces naeslundiis* with MIC of 62.5 μg/mL (Liu et al. 2009). The other diterpenoid, 19-β-L-3′-acetoxyarabinofuranosyl-*ent*-kaur-16-ene-19-oate, exhibited strong activity against *S. mutans* and *A. naeslundiis* with MIC of 15.6 μg/mL.

Proteinase Inhibitory Activity

Arrowhead was reported to contain double-headed and multifunctional proteinase inhibitors APIA and APIB consisting of 179 amino acid residues with three disulfide bonds (Yang et al. 1992; Xu et al. 1993; Luo et al. 1997). Earlier studies by Chi et al. (1985) found that APIB consisted of 141 amino acid residues; 20 pairs amino acid residues were repeated in the molecule of this inhibitor. Three of these pairs even occurred three times, suggesting that this arrowhead inhibitor may belong to a new family. Inhibitor APIA inhibited an equimolar amount of trypsin and chymotrypsin simultaneously and weakly inhibited kallikrein, while inhibitor APIB inhibited two molecules of trypsin simultaneously and inhibited kallikrein more strongly than did inhibitor APIA (Yang et al. 1992). Both inhibitors consisted of 150 amino acid residues with three disulfide bonds (Cys 43-Cys 89, Cys 110-Cys 119, and Cys 112-Cys 115) and share 90 % sequence identity, with 13 different residues. Both inhibitors were found having the same cDNA sequence and genomic structures. Though they share 91 % homology, they are different in inhibitory activities (Xie et al. 1997). Lys-44 and Arg-76 were found to be the reactive site of APIB and Ser-82 and Leu-87 for APIA. Studies by Li et al. (2002b) confirmed that Arg-76 and Arg-87 but not Lys-44 were definitely the reactive sites of APIB and Leu-87 in APIA. Subsequent studies by Li et al. (2002a) found that the inhibitory specificity of arrowhead protease inhibitors A and B (APIA and APIB) were modulated by conformation around tryptophan residues. Jiang et al. (2008) reported that arrowhead protease inhibitor A (API-A), a member of the serine protease inhibitor family, could inhibit two trypsin molecules simultaneously. Further studies by Bao et al. (2009) found that the ternary structure revealed that the two trypsins bind on opposite sides of API-A and were 34 A apart. The two P1 residues were unambiguously assigned as Leu(87) and Lys(145), and their identities were further confirmed by site-directed mutagenesis.

Traditional Medicinal Uses

The plant is antiscorbutic, laxative, tonic and diuretic. The leaf is used to treat a range of skin problems (Duke and Ayensu 1985). The tuber is regarded as discutient and galactagogue and may induce premature birth. *S. trifolia* essential oil is used medicinally during childbirth and for skin diseases in Chinese traditional medicine (Zheng et al. 2006). In Vietnam, the plant is used to treat dizziness or to apply on pimples (Tanaka and Nguyen 2007).

Other Uses

Aerial parts of Chinese arrowhead are fed to cattle in parts of India and Southeast Asia and also to pigs.

Comments

Most specimens determined as *Sagittaria sagittifolia* are, in fact, this taxon (Wang et al. 2010).

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Allium ampeloprasum

Scientific Name

***Allium ampeloprasum* L.**

Synonyms

Allium adscendens Kunth, *Allium albescens* Guss., *Allium ampeloprasum* f. *holmense* (Asch. & Graebn.) Holmboe, *Allium ampeloprasum* subsp. *euampeloprasum* Hayek, nom. inval., *Allium ampeloprasum* subsp. *halleri* Nyman, *Allium ampeloprasum* subsp. *porrum* (L.) Hayek, *Allium ampeloprasum* subsp. *thessalum* (Boiss.) Nyman, *Allium ampeloprasum* var. *babingtonii* (Borrer) Syme, *Allium ampeloprasum* var. *bertolonii* (De Not.) Nyman, *Allium ampeloprasum* var. *bulbiferum* Syme, *Allium ampeloprasum* var. *bulgaricum* Podp., *Allium ampeloprasum* var. *caudatum* Pamp., *Allium ampeloprasum* var. *gasparrinii* (Guss.) Nyman, *Allium ampeloprasum* var. *gracile* Cavara, *Allium ampeloprasum* var. *holmense* Asch. & Graebn., *Allium ampeloprasum* var. *porrum* (L.) J. Gay, *Allium ampeloprasum* var. *pylium* (De Not.) Asch. & Graebn., *Allium ampeloprasum* var. *wiedemannii* Regel, *Allium ascendens* Ten., *Allium babingtonii* Borrer, *Allium bertolonii* De Not., *Allium byzantinum* K. Koch, *Allium duriaeanum* Regel, *Allium durieuanum* Walp., *Allium gasparrinii* Guss., *Allium halleri* G. Don, *Allium holmense* Mill. ex Kunth, *Allium kurrat* Schweinf. ex K. Krause, *Allium laetum* Salisb., *Allium lineare* Mill., *Allium porraceum* Gray, *Allium porrum* L., *Allium porrum* subsp. *euampeloprasum* Breistr., *Allium porrum* var. *ampeloprasum* (L.) Mirb., *Allium porrum* var. *kurrat* (Schweinf. ex K. Krause) Seregin, *Allium pylium* De Not., *Allium scopulicola* Font Quer, *Allium scorodoprasum* subsp. *babingtonii* (Borrer) Nyman, *Allium spectabile* De Not., *Allium syriacum* Boiss., *Allium thessalum* Boiss., *Porrum amethystinum* Rchb., *Porrum ampeloprasum* (L.) Mill., *Porrum commune* Rchb., *Porrum sativum* Mill.

Family

Amaryllidaceae, also placed in Alliaceae

Common/English Names

Broadleaf Wild Leek, Elephant Garlic, English Leek, European Leek, Great-Headed Garlic, Great round-headed Leek, Kurrat, Kurrat Leek, Levant Garlic, Pearl Onion, Wild Leek

Vernacular Names

Afrikaans: Prei
Albanian: Pras, Presh
Arabic: Baṣṣal Al Afrīt. Tum-Zu El-Raas, Kurrat
Austrian: Lauch
Basque: Porru

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Belarusian: Poréi, Tsabulevaja
Belgian: Porei
Bosnian: Pori Luk, Prasa, Praziluk
Brazil: Alho-Poró
Bulgaria: Praz, Праз Praz
Catalan: Porro
Chinese: Da Tou Suan, Hsieh Ts'ung, Jiu Cong, Ou Zhou Jiu, Xie Cong, Xi Yang Cong
Croatian: Divlji Luk, Divji Vinogradski Puri, Glavati Purić, Luk, Luk Purić, Luk-Por, Naljutka, Perati Luk, Poljski Češnjak, Pori Luk, Porić, Porjak, Porluk, Prasluk, Praziluk, Prazluk, Prdeći Žbun, Purić, Purić Luk, Purjak Lučac, Lučec, Luk Purić, Purić, Vinogradski Luk, Vinogradski Porjak
Czech: Pór, Pór Zahradní, Pór Zahradní Setý, Pór Zahradní Stockholmský
Danish: Orientalsk Løg, Perleløg Porre, Vild Perleløg
Dutch: Prei, Wilde Prei, Wild Look, Grootkoppige Knoflook, Olifantsknoflook
Eastonian: Hobulauk, Pärlsibul, Porrulauk, Suvi-Porrulauk
Esperanto: Ajlo Dentita, Ampeloprazo, Poreo
Farsi: Gandana, Tarché Farangy
Finnish: Kesäpurjo, Purjo, Purjosipuli
French: Ail À Grosse Tête, Ail d'Orient, Ail Faux Poireau, Ail Gros, Carambole, Faux Poireau, Petit Poireau Antillais, Poireau, Poireau D'été, Poireau Du Levant, Poireau Perpetuel, Poireau Sauvage, Porreau
Gaelic: Cainneann
Galician: Porreta
Georgian: Prása, Prassa
German: Ackerknoblauch, Ackerlauch, Aschlauch, Breitlauch, Breitblättriger Wilder Lauch, Fleischlauch, Gartenlauch, Gemüse-Lauch, Küchenlauch, Lauch, Porree, Porree Lauch, Praso, Perllauch, Pferdeknoblauch, Sommer-Knoblauch, Sommerlauch Spanischer Lauch, Suppen-Lauch, Wilder Lauch, Winter-Lauch, Winterlauch
Greek: Ampelopraso, Praso
Hebrew: Karrash, Kereshah, Shum Gavohah, Shum Hakarash
Hungarian: Francia Hagyma, Gyöngyhagyma, Póréhagyma
Icelandic: Blaðylaukur
India: Ailiyama Ēmapōlōprāsama, Gandha, Gandana, Kirath (Hindi), Maroy Napakpi (Manipuri), Khorat (Marathi), Iraakuuccittam (Tamil), Bara Sir Wala Lasan (Urdu)
Indonesia: Bawang Péré, Bawang Prei, Bawang Sayur
Italian: Porro, Porraccio, Porrandello, Porraccio, Porro Selvatico
Japanese: Liiki, Nira Negi, Seiyou Negi
Kashmiri: Godu
Kazakh: Luk Porej
Kenya: Gĩtũngũrũ (Gikuyu)
Khmer: Khtum-Khchal
Kirghiz: Porej Pijazi
Kiribati: Rike
Laotian: Pèènz Fàlangx
Latvian: Puravi, Sīpoli
Macedonian: Golemoglavest Luk, Običen Praz
Maltese: Kurrat Slavagg
Malaysia: Bawang Prei, Bawang Sayuran, Lik
Maori: Riiki
Mongolian: Songino
Norwegian: Perleløk, Purre
Persian: Tareh
Polish: Czosnek Dziki, Czosnek Por, Por, Por Dziki
Portuguese: Ail À Grosse Tête, Alho Bravo, Alho-De-Verão, Alho-Françês, Alho Gigante, Alho-Inglês, Alho-Ordinário, Alho Porro, Chalotes, Porreta, Porro-Hortense, Porro-Pratense, Porros-Bravos
Philippines: Leek, Sibuyas-Bisaya (Bisaya), Kutsai (Tagalog), Kuse (Pampangan), Kusay (Pangasinan)
Russian: Luk Porej, Luk Porei, Luk Vinogradnyj
Serbian: Čapljan, Čapljani Luk, Divlji Luk, Luk, Lukomača, Sitna Ljutika, Velja Ljutika, Vinogradski Luk, Por, Porik, Pras, Prasji Luk, Praz, Praziluk, Purjan, Zeleni Luk
Slovaščina: Pasji Luk, Poletni Luk, Por
Sorbian: Porej
Spanish: Aho Porro, Ajo Chilote, Ajo Elefante, Ajoporro, Ajoporro Silvestre, Cebolla Puerro, Cebolla Silvestre, Porro Silvestre, Puerro Agreste, Puerro Salvage, Puerro Silvestre
Swahili: Namna Ya Kitunguu Kidogo, Vitunguu Liki
Swedish: Pärllök, Purjo, Purjolök, Vild Purjolök
Swiss: Poireau
Taiwan: Jiu Cong, Yang Cong

Tajik: Siri Tez
Thailand: Krathiam-Ton, Krathiam Tai, Krahtiam-Bai, Kra Thiam Thon Hua Yai
Tibetan: Ñūqtsoon
Turkish: Bağ Pirasasi, Karaköremen, Kaya Sarımsağı, Keçi Körmeni,Yabani Pırasa, Yalanci Pirasa, Yaz Sarmisaği, Yaz Sarmaşiği
Turkmen: Ýapyşak Şogan
Ukrainian: Cibulja-Porej
Welsh: Cenhinen, Cenhinen Gyffredin, Cenhinen Wyllt, Cennin, Craf-Y-Geifr, Garlleg Mawr Pengrwn, Nionyn Dodwy
Wolof: Poro
Vietnamese: Lò Chân Lông, Poa-Rô Hành, Tỏi Tây
Xhosa: Iliki, Uhlobo Oluthile Lwetswele
Yiddish: Pureh-Tsibehleh

Origin/Distribution

Allium ampeloprasum sensu lato consist of a cohort of wild ecotypes and cultivated plants, originating from an area extending from Iran to Portugal and Northern Africa. Bulbous leek has been long cultivated by ancient Egyptians, Greeks and Romans. Bulbous and non-bulbous leek is cultivated nowadays on all continents throughout the world. Leek is cultivated in many European countries, especially in Western Europe, and in North America and Australia, more seldom elsewhere in the world.

Agroecology

In its native range, leek (Plate 1) occurs in open disturbed areas and roadsides. Its optimum temperature range is 20–30 °C with night temperature of 22 °C and day temperature of 30 °C. A cool season of at least 4 months is needed for good growth of leek. Leek is cultivated in the higher altitude above 1,000 m in the tropics. Leek cultivation in hot humid lowlands below 500 m is rarely successful. It grows on any soil types but does best in friable, deep, well-drained soils rich in organic matter and with pH above 5.6.

Weibe (1994) found that leek may have an obligatory vernalisation requirement, whereas the effects of day length were quantitative only. Optimum vernalisation temperature was determined at 5 °C and the inductive temperature ranging between 0 and 18 °C. Temperatures above 18 °C caused devernalisation, and bolting was promoted by short days during and long days after vernalisation.

Plate 1 Leek plant in situ

Edible Plant Parts and Uses

The non-bulbous (Plate 2) and bulbous (Plate 3) pseudostem and lower blades of foliage leaves and the green leaves are consumed as vegetables. They can be used sliced and eaten raw in salads or as flavouring or pickled but are usually cooked in soups or stir-fried. In Asia, leek is usually eaten cooked in soups or with noodles or stir-fried with meat or seafood. The flowers are also edible but are seldom produced. Leeks are an ingredient of cock-a-leekie soup, leek and potato soup and *vichyssoise*, as well as plain leek soup.

Plate 2 Leeks with swollen non-bulbous pseudostem

Plate 3 Leek with bulbous pseudostem

One of the most popular uses is for adding flavour to stock. The dark green portion is usually discarded because it has a tough texture, but it can be sautéed or added to stock. Leeks are much relished in Turkish cuisine. Some popular dishes are *Zeytinyağlı pırasa* (leek with olive oil), *Ekşili pırasa* (sour leek), *Etli pırasa* (leek with meat), *Pırasa Musakka* (leek musakka), *Pırasalı börek* (börek with leek) and *Pırasa köftesi* (cooked leek meatball). The bulbils have a mild garlic flavour and make a nice flavouring in salads and cooked foods but are too fiddly to use because of their small size. Leeks are also extensively used in Welsh cuisine.

Allium porrum has been widely used in Persian foods as a flavour component (Movahedian et al. 2006). Persian leek is commonly used in soups, pottage and hash (Rojhan 1981). Fermentation of leek afforded opportunities in view of biomass valorisation and product diversification (Wouters et al. 2013). A preliminary sensory analysis revealed that the spontaneously fermented leek and the one obtained with the mixed starter culture were preferred by consumers, emphasising again the importance of microbial successions in vegetable fermentations. The mixed starter culture of *Lactobacillus plantarum* IMDO 788 and *Lactobacillus mesenteroides* IMDO 1,347 was most promising, as its application resulted in fermented leek of good microbiological quality and in a more extensive carbohydrate consumption, whereby diverse end metabolites were produced.

Botany

A biennial, robust, odorous, erect herb growing to 60–100 cm high (Plates 1 and 5). The true stem consisting only of a basal plate or disc, with little or no bulb formation (Plate 2) or with bulbs producing two kinds of cloves, small stiped ones and larger sessile ones, and with adventitious roots (Plate 4). The bulb is solitary, cylindrical ovoid to subglobose (Plate 3), sometimes bearing bulbels; covered by a white, membranous entire coat. Leaves 6–9, distichously alternate; sheath tubular, forming a pseudostem up to 60 cm long; blade linear to linear-lanceolate, flat, up to 50 cm × 7 cm, keeled, V-shaped in cross-section. Inflorescence a globose umbel, 4–12 cm across, compact, consisting of several hundreds of flowers (Plate 6), on a solid, terete scape up to 100 cm long; umbel subtended by a single, long-beaked spathe shed at flowering. Flowers bisexual, campanulate; pedicel 1–5 cm long; tepals 6, in 2 whorls, free, ovate-oblong, 4–6 mm long, pink, purple or white; stamens 6, the inner ones tricuspid; ovary ovoid–globose, superior, 3 celled with transversely convex nectaries near middle of septa. Linear style exserted with capitate stigma. Fruit a depressed globose to ovoid capsule 2–4 mm across, with up to six seeds. Seeds small, 2–3 mm × 2 mm, black.

Plate 4 Leek adventitious roots

Plate 5 Harvested leeks

Plate 6 Leek inflorescence

Nutritive/Medicinal Properties

The nutrient composition of raw leek bulb and lower leaf portion per 100 g edible portion minus the top, root ends and skin (USDA-ARS 2014) was reported as: water 83 g, energy kcal 61 (255 kJ), protein 1.50 g, total fat 0.30 g, ash 1.05 g, carbohydrate 14.15 g, total dietary fibre 1.8 g, total sugars 3.90 g, Ca 59 mg, Fe 2.10 mg, Mg 28 mg, P 35 mg, K 180 mg, Na 20 mg, Zn 0.12 mg, Cu 0.120 mg, Mn 0.481 mg, Se 1.0 µg, vitamin C 12 mg, thiamine 0.060 mg, riboflavin 0.030 mg, niacin 0.400 mg, pantothenic acid, 0.140 mg, vitamin B6 0.233 mg, folate 64 µg, choline 9.5 mg, β-carotene 1,000 µg, lutein + zeaxanthin 1,900 µg, vitamin A 1,667 IU, vitamin A 83 µg RAE, total vitamin E (α-tocopherol) 0.92 mg and vitamin K (phylloquinone) 47.0 µg; total saturated fatty acids 0.040 g, 16:0 (palmitic acid) 0.038 g and 18:0 (stearic acid) 0.002 g; total monounsaturated fatty acids 0.004 g, 18:1 undifferentiated (oleic acid) 0.004 g; total polyunsaturated fatty acids 0.166 g, 18:2 undifferentiated (linoleic acid) 0.067 g and 18:3 undifferentiated (linolenic acid) 0.099 g; and tryptophan 0.012 g, threonine 0.063 g, isoleucine 0.052 g, leucine 0.096 g, lysine 0.078 g, methionine 0.018 g, cystine 0.025 g, phenylalanine 0.055 g, tyrosine 0.041 g, valine 0.056 g, arginine 0.078 g, histidine 0.025 g, alanine 0.074 g, aspartic acid 0.140 g, glutamic acid 0.226 g, glycine 0.069 g, proline 0.066 g and serine 0.092 g. Eighty per cent of the total lipids of *Allium cepa*, *Allium sativum* and *Allium porrum* were found to consist of four fatty acids: linoleic (46–53 %), palmitic

(20–23 %), oleic (4–13 %) and α-linolenic acid (3–7 %) (Tsiaganis et al. 2006). In leek, 50 fatty acids were determined, 12 of that above 0.4 % and 4 above 2.5 %. Phospholipids consisted of a limited number of specific fatty acids, while neutral lipids contained a wide range including some unusual fatty acids.

Green leaves of leek mainly contained kaempferol glycosides, predominated by mono- and diglycosides such as kaempferol-3-β-D-glucoside and kaempferol-3-xylosyl-β-D-glucoside (Starke and Herrmann 1976). In leek glucose was dominant as sugar component compared to xylose. Traces of quercetin-3-glucoside were identified, but no spiraeoside (quercetin-4′-glucoside) was detected. Leek bulb only few milligramme of glycosides of kaempferol and quercetin per kg fresh weight. Flavonols kaempferol 2.7 mg, myricetin 0.2 mg and quercetin 0 mg were found in leeks (Hertog et al. 1992; Lugasi and Hovari 2000; Kevers et al. 2007). Five flavonoid glycosides based on the kaempferol aglycone were isolated from leek bulbs, and two of them were new compounds and identified as kaempferol 3-*O*-[2-*O*-(*trans*-3-methoxy-4-hydroxycinnamoyl)-β-D-galactopyranosyl]-(1→4)-*O*-β-D-glucopyranoside and kaempferol 3-*O*-[2-*O*-(*trans*-3-methoxy-4-hydroxycinnamoyl)-β-D-glucopyranosyl]-(1→6)-*O*-β-D-glucopyranoside (Fattorusso et al. 2001). A set of secondary metabolites was identified from the aerial part of *Allium porrum*: monohexose, dihexose and coumaroyl, feruloyl and caffeoyl acylated dihexose derivatives of kaempferol (Donna et al. 2014). The total concentration of carbohydrates (glucose, fructose, kestose/nystose and sucrose) and nine amino acids (glutamine, arginine, alanine, threonine, valine, leucine, lysine, phenylalanine, tyrosine) varied by fourfold in leek juice from different cultivars, while the total concentrations of four organic acids (pyruvic acid, malic acid, fumaric acid, α-hydroxybutyrate) were similar in all cultivars (Soininen et al. 2014). All the quantified flavonols were kaempferol derivatives or quercetin derivatives; the most abundant were kaempferol derivatives (including kaempferol hexose, kaempferol dihexose, kaempferol trihexose), but quercetin-malonyl-dihexose, kaempferol-malonyl-dihexose 1 and 2 and kaempferol-malonyl-hexose were also detected.

Fructans were the only nonstructural carbohydrates detected apart from glucose, fructose and sucrose in *A. porrum* (Darbyshire and Henry 1981). The maximum DP (degree of polymerisation) detected was 12. No starch or members of the raffinose series of oligosaccharides were detected. The trisaccharides, 1^F-fructosylsucrose and 6^G-fructosylsucrose were also detected. Fructan-type oligosaccharide (FTO) 3–10 g/100 g FW was found in leek bulb and the chain length distribution in comprised, DP (degree of polymerisation) 3–5 = 50 %, 6–12 DP = 50 % (Muir et al. 2007; Judprasong et al. 2011). Leek contained large amounts of FTO with DP ranging from 3 to 12 (up to 10 % FW) and a fructan profile similar to onions. The four FTO series, namely, 1-kestose type, an inulin series with the general formula G-1, 2 – 1, $_n$ (2 –F-1), 2-F(G-1, 2-F = sucrose); 6-ketose type, a neokestose-based series with chain elongation only at the glucose end of the original sucrose molecule F-2,$_m$ (1-F-2), 1-F-2, 6-G-1, 2-F; mixed type a neokestose-based series with elongation from both sides of the sucrose F-2,$_m$ (1-F-2), 1-F-2, 6-G-1, 2-F-1, $_n$(2-F-1),2-F; and neoseries, an inulo-*n*-ose series without a terminal glucose F-1,(2-F-1)$_n$,2-F were present in leek although neoseries were dominant (Ernst et al. 1998).

Total concentrations of S-alk(en)yl-L-cysteine sulfoxide (ACSO), namely, methyl cysteine sulfoxide (MCSO), 2-propenyl cysteine sulfoxide (2-PeCSO), 1-propenyl cysteine sulfoxide (1-PeCSO) and propyl cysteine sulfoxide (PCSO), in leek pseudostems, roots and leaves were 0.31, 0.39 and 0.36, respectively (Hovius et al. 2005). The most abundant ACSO in leek tissues was 1-PeCSO and MCSO. The concentration of 1-PeCSO in leek pseudostems, roots and leaves was 0.14, 0.10 and 0.14, respectively. Fritsch and Keusgen (2006) found that pearl onion and leek (*A. ampeloprasum*) had higher relative amounts of cysteine sulfoxides methiin and propiin, respectively. The content of S-alk(en)ylcysteine-S-oxides in *Allium* species (leek, garlic

and onion) varied between 0.59 and 12.3 mg/g fresh weight (Kubec and Dadáková 2008). Whereas alliin was found only in garlic, isoalliin was the major S-alk(en)ylcysteine-S-oxide in onion, leek, chive and shallot. A detailed analysis of leek cultivar "Tadorna" leaves showed that total S-alk(en)yl-L-cysteine sulfoxides (RCSOs) concentrations decreased acropetally (Doran et al. 2007). Profiles were composed of (±)-methyl-L-cysteine sulfoxide, (±)-ethyl-L-cysteine sulfoxide, (+)-propyl-L-cysteine sulfoxide and (+)-1-propenyl-L-cysteine sulfoxide (MCSO, ECSO, PCSO and 1-PeCSO, respectively). (+)-PCSO was the most prominent in green (2.4 mg/g FW), yellow (5.5 mg/g FW) and white (3.8 mg/g FW) tissues. The prop(en)yl-L-cysteine sulfoxide derivatives were dominant in tissues that had photosynthetic capacity. The (+)-MCSO levels were high in the bulb (3.6 mg/g FW). Detectable levels of (±)-ECSO were determined in the leaves (approximately 0.5 mg/g FW). RCSO profiles of the different tissue regions were similar, but more (+)-PCSO and (+)-1-PeCSO were detected in the bulb. In general, mature upper leaf tissues had lower levels of total RCSOs. A detailed analysis of leek cultivar "Tadorna" leaves showed that total S-alk(en)yl-L-cysteine sulfoxides (RCSOs) concentrations decreased acropetally (Doran et al. 2007). Profiles were composed of (±)-methyl-L-cysteine sulfoxide, (±)-ethyl-L-cysteine sulfoxide, (+)-propyl-L-cysteine sulfoxide and (+)-1-propenyl-L-cysteine sulfoxide (MCSO, ECSO, PCSO, and 1-PeCSO respectively). (+)-PCSO was the most prominent in green (2.4 mg/g FW), yellow (5.5 mg/g FW) and white (3.8 mg/g FW) tissues. The prop(en)yl-L-cysteine sulfoxide derivatives were dominant in tissues that had photosynthetic capacity. The (+)-MCSO levels were high in the bulb (3.6 mg/g FW). Detectable levels of (±)-ECSO were determined in the leaves (approximately 0.5 mg/g FW). RCSO profiles of the different tissue regions were similar, but more (+)-PCSO and (+)-1-PeCSO were detected in the bulb. In general, mature upper leaf tissues had lower levels of total RCSOs. The phenolic compounds (mg/kg DW) found in fresh, cut green leek leaves in order of importance were kaempferol 3-*O*-glucoside 31.92 mg, ferulic acid 27.07 mg, quercetin 3-*O*-galactoside 21.73 mg, sinapinic acid 3.76 mg, quercetin 2.67 mg, propyl gallate 2.09 mg, caffeic acid 0.93 mg, kaempferol 0.85 mg and luteolin 0.74 mg (Bernaert et al. 2013a). Fermentation of the green leek leaves increased the number and amount of several phenolic compounds. The phenolic compounds (mg/kg DW) found in green leek leaves after 21 days fermentation in order of importance were kaempferol 3-*O*-glucoside 50.25 mg, ferulic acid 37.70 mg, quercetin 3-*O*-galactoside 22.56 mg, hydroferulic acid 37.70 mg, quercetin 2.71 mg, propyl gallate 2.10 mg, quercetin 3-*O*-rutinoside 1.60 mg, caffeic acid 0.83 mg, kaempferol 0.79 mg, luteolin 0.84 mg, dihydroquercetin 0.73 mg, quercetin 3-*O*-arabinoside 0.55 mg and naringenin 0.23 mg, and sinapinic acid was not detected. The phenolic compounds (mg/kg DW) found in fresh, cut white shaft of leek in order of importance were ferulic acid 29.71 mg, quercetin 3-*O*-galactoside 23.23 mg, kaempferol 3-*O*-glucoside 3.50 mg, quercetin 2.63 mg, propyl gallate 2.11 mg, caffeic acid 1.03 mg, kaempferol 0.77 mg, luteolin 0.71 mg and naringenin 0.16 mg, and sinapinic acid, hydroferulic acid, quercetin 3-*O*-arabinoside, quercetin 3-*O*-rutinoside and dihydroquercetin were not detected. The phenolic compounds (mg/kg DW) found in leek white shaft after 21 days fermentation in order of importance were ferulic acid 45.05 mg, quercetin 3-*O*-galactoside 22.99 mg, hydroferulic acid 20.79 mg, kaempferol 3-*O*-glucoside 7.47 mg, quercetin 2.62 mg, propyl gallate 2.07 mg, caffeic acid 0.83 mg, kaempferol 0.71 mg, luteolin 0.71 mg and naringenin 0.23 mg, and sinapinic acid, quercetin 3-*O*-arabinoside, quercetin 3-*O*-rutinoside and dihydroquercetin were not detected. Tamping was responsible for great losses in polyphenol content. Total phenolic content in the green leaves at the end of fermentation was significantly higher compared with tamped samples. The contents of ferulic acid, astragalin and luteolin increased significantly by 39 %, 57 % and 13 %, respectively, after leek fermentation process for 3 weeks. Compared with initial

concentration, the tamping process also caused a significant decline in methiin and isoalliin contents of green leaves (62 and 32 %, respectively) and a decrease of 48 % and 32 %, respectively, in the white shaft. Three weeks of fermentation caused a decrease of 93 % of methiin and 100 % of isoalliin in the green leaves compared with fresh samples, while a reduction of 91 % of methiin and 100 % of isoalliin was found in the white shaft. White shaft is used in many culinary preparations, while the leaves deemed inferior are used for soups. Leek cultivar and tissue had an effect on the S-alk(en)yl-L-cysteine sulfoxides, i.e. isoalliin and methiin amounts (Bernaert et al. 2012b). Cultivars Artico and Apollo F1 rated highest for the mean isoalliin and methiin concentration, respectively. The isoalliin concentration of the white shaft and green leaves of the 31 leek cultivars varied from 15 to 53 mg/g dry weight (DW) and from 9 to 45 mg/g DW, respectively, whereas the methiin concentration varied from 3 to 16 mg/g DW and from 1 to 10 mg/g DW, respectively.

Apocarotenoids made up of cyclohexenone derivatives of mono- and diglycosides of 13-hydroxyblumenol C and blumenol C acylated with 3-hydroxy-3-methyl-glutaric and/or malonic acid that accumulated in the mycorrhizal roots of leek were: 13-hydroxyblumenol C-di-9,13-*O*-β-glucopyranoside; 13-hydroxyblumenol C-9-*O*-β-glucopyranoside; 13-hydroxyblumenol C-9-*O*-[3′-*O*-(3″-hydroxy-3″methylglutaryl)- β -glucopyranoside], 13-hydroxyblumenol C derivative; mixture of 13-hydroxyblumenol C and blumenol C derivatives; blumenol C 9-*O*-(6′-*O*-α-arabinopyransoyl-β-glucopyranoside); blumenol C 9-*O*-(4′-*O*-glucosyl-β-glucopyranoside); 13-hydroxyblumenol C 9-*O*-[3′-(3″-hydroxy-3″-methylglutaryl)-6′-*O*-malonyl-β-glucopyranoside]; blumenol C9-*O*-[3′-(3″-hydroxy-3″-methylglutaryl)-β-glucopyranoside; blumenol C 9-*O*-(6′-*O*-malonyl-β-glucopyranoside); and isomer of blumenol C 9-*O*-[3′-(3″-hydroxy-3″-methylglutaryl)-β-glucopyranoside (Schliemann et al. 2008). The content of mycorradicin derivatives remained low in the roots. Antifungal *N*-feruloyl amides *N*-feruloyltyrosine and *N*-feruloyl-tyramine were isolated from *A. porrum* roots (Fattorusso et al. 1999). A cinnamic imidate (1*Z*,2*E*)-methyl 3-(-*p*-hydroxy-*m*-methoxyphenyl)-*N*-(-*p*-hydroxyphenethyl) acrylimidate, named persicoimidate, and two cinnamic acid derivatives, *N*-feruloyl tyramine and *N*-caffeoyl tyramine, were isolated and characterised from bulbs and seeds of Persian leek, *Allium ampeloprasum* subsp. *persicum* (Sadeghi et al. 2013a).

Non-fertilised leek contained 20.4 g/kg of dry weight (DW) of *S*-alk(en)yl-L-cysteine sulfoxides (ACSOs) and 1.57 g/kg of DW ascorbic acid (Lundegårdh et al. 2008) The ACSOs comprised 92–96 % isoalliin, the rest being methiin. Alliin was identified in only 1 of 72 samples. The ACSO level was increased by 37 % by the mineral fertiliser. Whereas direct incorporation of red clover, mulch and red clover biodigestate had no influence on the ACSO level, the highest dose of compost increased the ACSO level by 55 %. Ascorbic acid levels were not influenced by the mineral treatment. Green manures increased ascorbic acid levels only on a dry weight basis. A high correlation between the content of sulfur and ACSO indicated that delivering capacity of sulfur from the manure to the plant strongly affected the ASCO content of the leek.

Allium species including *A. ampeloprasum* were reported to produce asymmetric aliphatic disulfides: methyl-allyl, methyl-*n*-propyl and allyl-*n* propyl disulfides (Jacobsen et al. 1964). Studies by Bernhard et al. (1964) confirmed that *Allium ampeloprasum* and *A. sativum* produced allyl monosulfide and allyl alcohol. A volatile compound 3, 4-dimethyl-2, 5-dioxo-2, 5-dihydrothiophene was identified in leek (Albrand et al. 1980). When crushed, the leek emitted propyl propanethiosulfinate (Auger et al. 1989). Propyl propanethiosulfmate was found to be the most attractive substance for the leek moth *Acrolepiopsis assectella* but appeared to be repulsive on *Ephestia kuehniella*. Pearl onion and leek (*A. ampeloprasum*) were reported to have higher relative amounts of methiin and propiin, respectively (Fritsch and Keusgen 2006).

The potent odorant 3-mercapto-2-methylpentan-1-ol was detected in Leek (Granvogl et al. 2004). Studies by Ferary et al. (1996) found that *A. porrum* odours contained only thiopropanal *S*-oxide and

thiosulfinates as sulfur volatiles. The contents of sulfides from jumbo leek (*Allium ampeloprasum*) were dimethyl disulfide (1.7 mg/kg wet wt), methyl propenyl disulfide (15.7 mg/kg), propyl propenyl disulfide (7.5 mg/kg), dimethyl trisulfide 21.5 mg/kg), methyl propyl trisulfide (10.0 mg/kg) and methyl propenyl trisulfide (14.0 mg/kg) (Uchida et al. 2009a). The composition of alk(en)yl-cysteine sulfoxide from jumbo leek was *S*-methyl cysteine sulfoxide (4.1 mg/kg wet wt), *S*-propyl cysteine sulfoxide (0.1 mg/kg) and *S*-propenyl cysteine sulfoxide (2.44 mg/kg). The total content was the same as those of *A. cepa* L. and *A. ampeloprasum* L. Moreover, *N*-(γ-glutamyl)-*S*-(*E*-1-propenyl) cysteine (Glu-PEC, 87 mg/kg wet wt), an alk(en)yl-cysteine precursor from jumbo leek, was also detected. The lower odour producing mechanism in jumbo leek was determined to be the same as that in broadleaf wild leek (*A. ampeloprasum*); the substrate precursor Glu-PEC was converted to *S*-*E*-1-propenyl cysteine by γ-glutamyl transpeptidase. Then, *S*-*E*-1-propenyl cysteine was oxidised to *S*-propenyl cysteine sulfoxide, a substrate for alliinase. *S*-propenyl cysteine sulfoxide, another naturally present alk(en)yl-cysteine sulfoxide, was converted to *S*-alk(en)yl acid by alliinase(C-S lyase), followed by sulfide production via formation of the dialkyl thiosulfinates. The essential oils of *A. porrum* were characterised by the presence of dipropyl disulfide, dipropyl trisulfide and dipropyl tetrasulfide (Casella et al. 2013).

The steroid saponins oleanolic acid and gitogenin were found in leek (Smoczkiewicz et al. 1982). From *Allium ampeloprasum* bulbs, a new spirostane-type saponin, named ampeloside Bs_1, and two new furostane-type saponins, named ampeloside-Bf_1 and ampelosid-Bf_2, were isolated along with a known spirostane-type saponin, the prosapogenin of aginoside (Morita et al. 1988). The structures of the new saponins were established as agigenin 3-*O*-β-glucopyranosyl(1→3)-β-glucopyranosyl(1→4)-β-galactopyranoside, (25*R*)-26-*O*-β-glucopyranosyl-22-hydroxy-5α-furostane-2α, 3β, 6β, 26-tetraol-3-*O*-β-glucopyranosyl(1→3)-β-glucopyranosyl-(1→4)-β-galactopyranoside and (25*R*)-26-*O*-β-glucopyranosyl-22-hydroxy-5α-furostane-2α, 3β, 6β, 26-tetraol-3-*O*-β-glucopyranosyl(1→4)-β-galactopyranoside, respectively.

Steroid glycosides found in leek included: aginoside, a diosgenin glycoside C_{39} H_{64} O_{15}, ampeloside B_{S1}, ampelosideB_{f1} and ampeloside B_{f2} (Kravets et al. 1990). Four sapogenins, porrigenins A and B, identified as (25*R*)-5α-spirostan-2β,3β,6β-triol and (25*R*)-2-oxo-5α-spirostan-3β,6β-diol, respectively, and neoporrigenins A and B were also isolated from *Allium porrum* (Carotenuto et al. 1997b). Additionally, the known agigenin and its 25S epimer, neoagigenin, were also identified. Two other sapogenins, 12-keto-porrigenin (1a) and 2,3-seco-porrigenin (2a), isolated from the organic leek extract were identified as (25*R*)-5α-spirostan-3β, 6β-diol-12-one (1a) and (25*R*)-5α-2,3-secospirostan-2,3-dioic acid-6β-hydroxy-3,6-γ-lactone (2a) (Carotenuto et al. 1997a). Small amounts of the 25S epimers of both sapogenins were also found in the extract. Carotenuto et al. (1999) isolated four spirostanol saponins from leek bulbs; two of them were new compounds and were identified as (25*R*)-5α-spirostan-3β,6β-diol 3-*O*-{*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xylopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside} and (25*R*)-5α-spirostan-3β, 6β-diol 3-*O*-{*O*-β-D-glucopyranosyl-(1→3)-*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xylo pyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside}, a steroidal saponin isolated previously by Minaki et al. (1995) and F-gitonin isolated previously by Kawasaki et al. (1965). Three new steroidal saponins named yayoisaponins A–C were obtained together with the known dioscin and aginoside from elephant garlic (Sata et al. 1998). The structure of yayoisaponin A was determined as 3-*O*-β-D-glucopyranosyl-(1→3)-β-D-glucopyranosyl-(1→2)-[β-D-xylopyranosyl-(1→3)]-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside; yayoisaponin B as porrigenin B 3-*O*-β-D-glucopyranosyl-(1→3)-β-D-glucopyranosyl-(1→2)-[β-D-xylopyranosyl-(1→3)]-β-D-glucopyranosyl-(1→4)- β-D-galactopyranoside; and yayoisaponin C as agigenin 3-*O*-β-D-glucopyranosyl-(1→2)-[β-D-glucopyranosyl-(1→3)]-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside. A novel sapogenin named porrigenin C and its 25*S*

epimer were isolated from leek, together with the previously described sapogenins and the known compounds agigenin, diosgenin, β-chlorogenin and 24-ethylcholesta-(6-acyl)-3-*O*-β-D-glucoside (Fattorusso et al. 1998). Eight saponins (1–8) were isolated from leek bulbs, four of them (5–8) being novel compounds (Fattorusso et al. 2000). Compounds 5 and 6, possessing the same tetrasaccharide moiety of compounds 1 and 3, displayed very unusual spirostane aglycones, 12-keto-porrigenin and 2,12-diketoporrigenin (named porrigenin C), respectively. Compounds 7 and 8 were rare cholestane bidesmosides possessing a di- and trisaccharide residues linked to a polyhydroxycholesterol aglycone, respectively. Compound 7 was (22*S*)-cholest-5-ene-1β,3β,16β,22-tetrol 1-*O*-α-L-rhamnopyranosyl 16-*O*-β-D-glucopyranoside. Seven steroidal saponins were isolated from *A. ampeloprasum* bulbs (25*R*)-5α-spirost-5-en-3β-ol (diosgenin); *O*-α-L-rhamnopyranosyl–(1→4)-β-D-glucopyranoside (dioscin), (25*R*)-5α-spirostane-2α,3β,6β-triol (agigenin), 3-*O*-{*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xylopyransoyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside} (aginoside),agigenin3-*O*-{*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xyloglucopyransoyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside} (yayoisaponin C), (25*R*)-26-*O*-β-D-glucopyranosyl-22-*O*-methyl-5α-furostane-2α,3β,6β, 22α,26-pentol 3-*O*-{*O*-β-D- glucopyranosyl-(1→2)-*O*-[β-D-xylopyranosyl-(1→3)]-*O*-β-D- glucopyranosyl –(1→4)- β-D-galactopyranoside and (25*R*)-26-*O*-β-D- glucopyranosyl-22-*O*-methyl-5α-furostane-3β,6β, 22α,26-tetrol 3-*O*-{*O*-β-D-glucopyranosyl-(1 → 2)-*O*-[β-D-xylopyranosyl-(1→3)]-*O*-β-D- glucopyranosyl –(1→4)- β-D-galactopyranoside (Mimaki et al. 1999). From the freeze-dried whole-bulb powder of jumbo leek, the known steroid saponin, karatavioside A was isolated (Uchida et al. 2009b).

Steroidal saponins with the following structures (3β,5α,6β,25*R*)-6-[(β-D-glucopyranosyl) oxy]-spirostan-3-yl *O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-glucopyranosyl-(1→3)]-β-D-galactopyranoside and 3-[(*O*-β-D-glucopyranosyl-(1→3)-β-d-glucopyranosyl-(1→2)-*O*-[*O*-β-D-glucopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranosyl)oxy]-2,6-dihydroxy-(2α,3β,5α,6β,25*R*)-spirostane were isolated from the bulbs of *Allium ampeloprasum* var. *porrum* (Adão et al. 2011a, b). A new steroidal saponin was isolated from leek bulbs and its structure determined as (3β,5α,6β,25R)-3-{(*O*-β-D-glucopyranosyl-(1→3)-β-D-glucopyranosyl-(1→2)-*O*-[*O*-β-D-glucopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→)-β-D-galactopyranosyl) oxy}-6-hydroxyspirostan-2-one (Adão et al. 2012).

Two new spirostane glycosides, persicosides A (1) and B (2); four new furostane glycosides, isolated as a couple of inseparable mixture, persicosides C1/C2 (3a/3b) and D1/D2 (4a/4b); and one cholestane glycoside, persicoside E (5), together with the furostane glycosides ceposides A1/A2 and C1/C2, tropeosides A1/A2 and B1/B2 and ascalonicoside A1/A2 were isolated from seeds of Persian leek *Allium ampeloprasum* subsp. *persicum* (Sadeghi et al. 2013b). The chemical structure of new compounds were identified as (25*S*)-spirostan-2α,3β,6β-triol 3-*O*-[β-D-glucopyranosyl-(1→3)] [β-D-xylopyranosyl-(1→2)]-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside (1), (25*S*)-spirostan-2α,3β,6β-triol 3-*O*-[β-D-xylopyranosyl-(1→3)] [α-L-rhamnopyranosyl-(1→2)]-β-D-glucopyranosyl-(1→4)-*O*-β-D-galactopyranoside (2), furosta-1β,3β,22ξ,26-tetraol 5-en 1-*O*-β-D-glucopyranosyl (1→3)-β-D-glucopyranosyl (1→2)-β-D-galactopyranosyl 26-*O*-α-L-rhamnopyranosyl (1→2)-β-D-galactopyranoside (3a,3b), furosta-2α,3β,22ξ,26-tetraol 3-*O*-β-D-glucopyranosyl(1→3)-β-D-glucopyranosyl(1→2)-β-D-galactopyranosyl 26-*O*-β-D-glucopyranoside (4a,4b) and (22*S*)-cholesta-1β,3β,16β,22β-tetraol 5-en 1-*O*-α-L-rhamnopyranosyl 16-*O*-α-L-rhamnopyranosyl (1→2)-β-D-galactopyranoside (5).

According to Block (1992), most of the non-protein sulfur in *Alliums* could be found in the form of four principal ACSOs: methyl (MeCSO), 2-propenyl (2-PeCSO), 1-propenyl (1-PeCSO) and propenyl (PCSO). 1-PeCSO was found in the highest concentration in onions, and 2-PeCSO was found in the highest concentrations in garlic

with only trace amounts in onions. Among three common *Allium* crops, the total ACSO concentration was generally highest in garlic, intermediate in onion and lowest in leek (Block 1992; Coley-Smith 1986). Of eight *Allium* species, garlic and giant garlic contained greatest amounts of total S-alk(en)yl-L-cysteine sulfoxides (ACSO) (5.0–11.7 mg/g); Chinese chive, dehydrator onion, leek and shallot had moderate amounts (2.0–5.0 mg/g); and Japanese bunching onion, onion (TG 1015Y) and chive leaves contained least amounts of total CSO (<2 mg/g) (Yoo and Pike 1998). AlCSO (S-allyl-L-cystine sulfoxide, alliin) was the major precursor in garlic and giant garlic (3.2–9.8 mg/g) and was also contained in chive and Chinese chive. PeCSO (S-propenyl-L-cysteine sulfoxide) was the main flavour precursor in onion, green onion, leek and shallot (0.3–2.2 mg/g) but also found in chive, Chinese chive, garlic and giant garlic. MeCSO (S-methyl-l-cysteine sulfoxide) was a major precursor in chive and Chinese chive (0.68–1.85 mg/g fresh wt.) and found in all eight species examined with less amounts. S-propyl CSO, however, was not found in any of these species.

The major volatiles in leek oil were dipropyl trisulfide, dipropyl disulfide and (*E*)-propenyl propyl disulfide (Schulz et al. 1998). According to the higher amount of leek chromosomes in the cell nucleus, the percentages of the measured sulfur volatiles in the interspecific hybrid between *Allium cepa* and *Allium porrum* material corresponded more to the leek than to the onion flavour profile.

1-propenyl-L-cysteine sulfoxide (PeCSO) was the main flavour precursor in onion, green onion, leek and shallot (0.3–2.2 mg/g) but also found in chive, Chinese chive, garlic and giant garlic (Yoo and Pike 1998). *S*-methyl cysteine sulfoxide (MeCSO) was a major precursor in chive and Chinese chive (0.68–1.85 mg/g fresh wt.) and found in garlic, onion and leek in lesser amounts. The most important aroma compounds in the freshly cut leek slices were dipropyl disulfide, methyl propenyl disulfide, pentanal, decanal and propyl propenyl disulfide in order of priority (Nielsen and Poll 2004). When stored frozen and unblanched for 12 months, the aroma composition changed, and the most important compounds became pentanal, decanal, 2,5-dimethyl furan, unknown compound I and dipropyl disulfide. Blanching before freezing prevented to some degree these changes but also reduced the perceived intensity of the aroma compounds. The most important aroma compounds in the blanched sample were dipropyl disulfide, unknown compound I, pentanal, 2,5-dimethyl furan and propyl propenyl disulfide. The aroma profile of unblanched leek slices changed from consisting of almost only sulfur compounds such as dipropyl disulfide [concentration in fresh leek (FL) = 0.197 mg/L, concentration after 12 months of frozen storage (12 M) = 0.0409 mg/L] and propyl (*E*)-propenyl disulfide (FL = 0.0437 mg/L, 12 M = 0.00452 mg/L) in the fresh leeks to being dominated by numerous saturated and unsaturated aldehydes, such as hexanal (FL = 1.53 mg/L, 12 M = 3.63 mg/L), (*E*,*E*)-2,4-nonadienal (FL = 0.000 mg/L, 12 M = 0.0647 mg/L) and (*E*,*E*)-2,4-decadienal (FL = 0.129 mg/L, 12 M = 0.594 mg/L) at the end of the storage period (Nielsen et al. 2003). The catalytic activity of lipoxygenase (LOX) diminished throughout frozen storage, but 25 % of the original activity was present after 12 months of storage. Total amount of sulfur compounds was influenced by storage time, slice thickness and atmosphere (concentration in fresh 4 mm slices = 17.8 mg/L, 4 mm 12 M (month storage) = 3.48 mg/L, fresh 15 mm slices = 2.48 mg/L, 15 mm 12 M = 0.418 mg/L and 15 mm N 12 M = 1.81 mg/L) (Nielsen et al. 2004a). The 4 mm slices significantly developed the most aldehydes after 12 M (total amount = 9.28 mg/L) compared to 15 mm 12 M (6.49 mg/L) and 15 mm N 12 M (4.33 mg/L). LOX activity was positively influenced by nitrogen packaging, and hydroperoxide lyase (HPL) activity was influenced by slice thickness, whereas alcohol dehydrogenase (ADH) was unaffected by both parameters. The total amount of sulfur compounds and the total amount of aldehydes were greatly influenced by storage time, atmosphere and blanching [concentration of sulfur compounds in fresh unblanched (UNB) slices = 1.35 mg/L, fresh blanched (B) slices = 1.09 mg/L, UNB 21 %

O_2 12 M = 0.656 mg/L, UNB 0 % O_2 12 M = 2.11 mg/L, B 21 % O_2 12 M = 1.14 mg/L, B 0 % O_2 12 M = 1.59 mg/L] (Nielsen et al. 2004c). The activities of HPL and alliinase were totally lost after 12 months, and ADH showed minimal activity, whereas LOX (UNB 0 % O_2) showed 25 % of the original activity. LOX was the most and HPL the least heat-labile enzyme investigated. The catalytic activity of LOX in leek tissues showed significant difference between linolenic acid (9.43×10^{-4} katals per kg protein) and linoleic acid (2.53×10^{-4} katals per kg protein), and the pH optimum of LOX was 4.5 – 5.5 against linoleic acid (Nielsen et al. 2004b). The catalytic activity of HPL was statistically the same for 9-(S)-hydroperoxy-(10*E*,12*Z*)-octadecadienoic acid (1.01×10^{-2} katals per kg protein) and 13-(S)-hydroperoxy-(9*Z*,11*E*)-octadecadienoic acid (7.69×10^{-3} katals per kg protein). ADH showed a catalytic activity of 5.01×10^{-4} katals/kg of protein towards hexanal. Linoleic acid resulted in significantly most hexanal, heptanal, (*E*)-2-heptenal, (*E*)-2-octenal, (*E*,*E*)-2,4-decadienal, pentanol and hexanol, whereas linolenic acid resulted in significantly most (*E*)-2-pentenal, (*E*)-2-hexenal, (*E*,*Z*)-2,4-heptadienal, (*E*,*E*)-2,4-heptadienal and butanol. Leek LOX produced only the 13-hydroperoxide of linoleic acid and linolenic acid.

The major polysaccharides in the leek were pectic substances – 23.3 %, which had a high degree of esterification (73–74 %) and cellulose 21.7 % (Kratchanova et al. 2008). The protein content of the leek was 24 %. Five pectic polysaccharide fractions of commensurate yields (2.4–3 %) were obtained. The obtained pectins differed in their polyuronic content (27.5–73.6), degree of esterification (12.6–76.6), neutral sugar content (18.4–71.1 %) and protein content (1.3–8.0 %). The highest polyuronic content was observed in the water- and chelate-extractable fractions. The acid- and alkaline-extractable pectic polysaccharides contained about 30 % uronic acids. In the polysaccharide fractions, a presence of glucuronic acid was observed. Its content was about 10 % of the total polyuronic acid content. Only the first two fractions had a high degree of esterification: 76.59 and 61.53 %. The first fraction had also very high protein content (8 %). In the other polysaccharides, the protein content was between 1.3 and 2.2 %. In the neutral sugar fraction, the prevailing sugar was galactose, followed by rhamnose. Extraction with diluted hydrochloric acid yielded polysaccharide with the highest neutral sugar content of 71.1 % and a low uronic acids content. The water- and chelate-extractable fractions had a lower L-rhamnose content (2.7 % and 2.9 %, respectively), and the other polysaccharide fractions from leek were characterised by a high L-rhamnose content (from 14 to 28 %). Further they reported that the water-extractable pectin had higher polyuronic content, higher protein content and lower neutral sugar content (Kratchanova et al. 2010). Next to galacturonic acid, they also contained glucuronic acid in the ratio 9:1 for the water-extractable polysaccharide and 3:1 for the acid-extractable polysaccharide. The main neutral sugar was galactose. The water-extractable pectic polysaccharide had higher molecular weight (10^6 Da) and homogeneity.

In leek seedlings, sterols were found to be present as a mixture in which (24*R*)-24-ethylcholest-5-en-3β-ol (around 60 %) was the major component (Moreau et al. 1998). The other sterols present were cholest-5-en-3β-ol; 24-methylcholest-5-en-3β-ol; (24*S*)-24-ethylcholesta-5,22*E*-dien-3β-ol; and stigmasta-5,24(24(1))*Z*-dien-3β-ol. These compounds were shown to reside mainly in the plasma membrane.

Leek leaf waxes consisted primarily of fatty acids (C16–22) and longer-chain (C26–31) derivatives (aldehydes, alkanes and ketones) (Rhee et al. 1998). $CHCl_3$-extractable lipids from the lower leaf segments were primarily hexadecanoic (C16) and octadecanoic (C18) acids. Smaller amounts of eicosanoic (C20) and docosanoic (C22) acids were also detected. The level of hexadecanoic and octadecanoic acids increased almost four- and twofold, respectively, from the bottom (segment I) to the top of the leaf (segment VII). Even though C16 and C18 fatty acids were a major component (78–92 %) of the $CHCl_3$-extractable surface lipids in the bottom 5 cm, they were minor components

(12–13 %) in the top 5 cm. Undetectable or very low levels (<5 % of the total wax load) of very long-chain alkanes, aldehydes and ketones were also observed in the bottom leaf segments. These components, however, increased dramatically in the middle region of the leaf to more than 75 % in the top 5 cm. Composition of epicuticular wax on segments of leek leaves IV (7–9 cm from leaf base) to VII (19,024 cm) consisted of hexadecanoic acid, octadecanoic acid, eicosanoic acid, docosanoic acid, hexacosanal, octacosanal, n-nonacosane, triacontanal, n-hentriacontane and hentriacontane-16-one. The following compounds were identified in leek leaves: bicyclo, hept-2-ene 0.56 %, thymol 3.68 %, 3-methyl-4-isopropylphenol 3.68 %, caryophyllene 3.63 %, naphthalene 23.27 %, copaene 2.96 %, cycloisolongofolene 4.76 %, 2-pentadecanone 1.96 %, N-hexadecanoic acid 2.49 %, phytol 3.16 % and 9,12,15-octadecatrienoic acid 0.82 % (Monemi et al. 2014). From leek callus, the following were identified: cyclotetrasiloxane 1 %, 2methyl 5 phenol 1.44 %, ethyl a-D-glucopyranoside 13.25 %, 2-methylindene 11.64 %, 9 methyl-3,4-dihydro-2H-pyrido 2.11 %, pentadecanoic acid 4.11 %, 2H-1-benzopyran 9.19 %, 3,4-dihydro H-cyclopenta 16 %, 9,12,octadecadienoic acid 2.43 %, 1,3,5 cycloheptatriene 1.20 %, 3,morpholine 5-methyl-6 phenyl 1.18 %, benzene 16.04 % and 1,2,benzenedicarboxyl 4.33 %.

Analysis of nectar from leek flowers revealed the presence of two major polypeptide bands of 50 kDa and 13 kDa, which were identified as subunits of alliin lyase (alliinase) and mannose-binding lectin, respectively (Peumans et al. 1997). The latter protein was particularly abundant since it accounted for about 75 % of the total nectar protein.

Antioxidant Activity

The ethanolic extract of leek leaf and stem exhibited 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging antioxidant activity with IC_{50} values of 98.90 g/mL and 61.05 g/mL, respectively (Mladenović et al. 2011). It contained high contents of phenols (69.46 mg GAE/g dry extract) and flavonoids (33.53 mg CE/g dry extract).

Green leek leaves were found to have significantly stronger antioxidant properties than the white shaft in the free radical scavenging activities against peroxyl (ORAC) and 2,2-diphenyl-1-picrylhydrazyl radicals (DPPH) and their Fe^{3+}-reducing capacity (FRAP) assays (Bernaert et al. 2011, 2012a). The antioxidant of the white shaft of leek cultivars to peroxyl radicals ranged from 26.91 to 88.07 μmol TE/g DW in the oxygen radical absorbance capacity (ORAC) assay. The antioxidant reducing potential of the white shaft ranged from 154.14 to 898.04 μM ferric reducing antioxidant power (FRAP). Correlation analysis between the total phenolic and L-ascorbic acid content and the antioxidant activity showed that phenolics and ascorbic acid contribute significantly to the antioxidant activity of leek. The three antioxidant activity assays were all correlated for the extracts of the white shaft of the 30 leek cultivars. The antioxidant capacity and the total content of phenolic compounds in the white shaft of the entire and packaged leek were stable during 13 days of refrigerated storage (Bernaert et al. 2013a). A significant increase in the concentration of isoalliin was observed. Significant differences could be observed in antioxidant properties of the entire and processed (green leaves removed)/packaged leek. The *S*-alk(en)yl-L-cysteine sulfoxide (ACSO) content (isoalliin and methiin) in the white shaft of packaged leek was significantly lower than the content in the white part of the entire leek. It was concluded that the minimal processing step of cutting the green leaves and roots had an influence on the levels of antioxidant properties. Application of fermentation resulted in a higher ORAC value and polyphenol content of the leek plant, especially in the green leaves (Bernaert et al. 2013b). The oxygen radical absorbance capacity (ORAC) increased by 62 % when the green leaves were fermented for 21 days, while 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity did not increase significantly.

Antimicrobial Activity

Steroidal saponins isolated from leek bulbs, ampeloside Bs_1, ampeloside-Bf_1 and the prosapogenin of aginoside did not inhibit growth of *Aspergillus niger*, but the spirostanol saponins ampeloside Bs_1 and the prosapogenin of aginoside were weakly inhibitory to growth of *Candida albicans* (Morita et al. 1988). The furostanol saponin ampeloside-Bf_1 was inactive. Four spirostanol saponins isolated from leek bulb, two new compounds (25*R*)-5α-spirostan-3β, 6β-diol3-*O*-{*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xylopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside} and (25R)-5α-spirostan-3β,6β-diol3-*O*-{*O*-β-D-glucopyranosyl-(1→3)-*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xylopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside}, a steroidal saponin isolated previously by Minaki et al. (1995) and F-gitonin isolated previously by Kawasaki et al. (1965) exhibited antifungal activity against *Fusarium culmorum* with ED_{50} values of 30–35 μg/mL (Carotenuto et al. 1999).

Allium ampeloprasum essential oil showed the strongest inhibitory effect against *Saccharomyces cerevisiae* at a concentration of only 1 % (Kocić-Tanackov et al. 2009). *Allium ampeloprasum* essential oil was inactive against the yeast *Candida tropicalis*, but another yeast *Rhodotorula* sp. was inhibited only by *A. ampeloprasum* essential oil. *Penicillium griseofulvum* was appreciably inhibited by *A. ampeloprasum* oil (78.3 % of inhibition, at a concentration of 10 %). The antimicrobial activity of elephant garlic (*Allium ampeloprasum* var. *ampeloprasum*) was stronger than ampicillin when used against *Escherichia coli*, *Bacillus subtilis*, *Bacillus thuringiensis*, *Staphylococcus actinomycete*s and gray Actinomycetes. It exhibited antibacterial effect against the common bacteria *Escherichia coli* and *Staphylococcus aureus* at a very low concentration (12.5 %).

Anticancer Activity

Sapogenin compounds isolated from *A. porrum*, agigenin and porrigenins A and B exhibited cytotoxicity and high antiproliferative activity on four different tumour cell lines WEHI 164 (murine fibrosarcoma), J-774 (murine monocyte/macrophage), IGR-1 (human melanoma) and P-388 (murine leukaemia) cell lines in-vitro (Carotenuto et al. 1997b). Two other leek sapogenins 12-keto-porrigenin and 2,3-seco-porrigenin exhibited antiproliferative activity on the same four tumour cell lines (Carotenuto et al. 1997a). Porrigenin C isolated from leek showed a considerable antiproliferative activity on the four tumour cell lines in-vitro (Fattorusso et al. 1998). Yayoisaponins A–C and aginoside, isolated from leek bulb, exhibited not only in-vitro cytotoxicity against P-388 cells at 2.1 μg/mL but also antifungal activity against *Mortierella ramanniana* at 10 μg/disc (Sata et al. 1998). Steroidal saponins from leek bulb diosgenin and a spirostanol saponin derivative exhibited appreciable cytostatic activity on human promyelocytic leukaemia HL-60 cells with IC_{50} values of 2.1 and 3.2 ug/mL, respectively (Mimaki et al. 1999). Elephant garlic extract inhibited the growth of human osteosarcoma cells, U2OS, by preventing the transition from G1 phase to S phase (Huang and Ren 2013). It reduced osteosarcoma cell, U2OS, invasion ability and significantly increased the proportion of apoptosis.

In a meta-analysis, consumption of high levels of *Allium* vegetables (onion, garlic, leek, Chinese chive, scallion, garlic stalk and Welsh onion) reduced the risk for gastric cancer risk (odds ratio, 0.54) (Zhou et al. 2011). Specific analyses for onion, garlic, leek, Chinese chive, scallion, garlic stalk and Welsh onion yielded similar results, except for onion leaf.

Hepatoprotective Activity

Both foam powder and freeze-dried powder obtained from jumbo leek (*A. ampeloprasum*) bulb decreased the induction of hepatocyte necrosis in D-galactosamine hydrochloride (GalN)-induced acute fulminant hepatitis and prevented the occurrence of ethanol-induced chronic liver disorders in rats by inhibiting the absorption of alcohol from the stomach (Uchida et al. 2009b).

Antiosteoporotic Activity

Oral administration of *Allium porrum* (250 and 500 mg/kg) had significant protective effect against osteoporosis induced by ethanol in rats (El-Shenawy et al. 2013). Administration of 20 % ethanol (3 g/kg) for 11 weeks led to a significant decrease in bone mineral density (BMD by 40 %); however, administration of leek extract (250, 500 mg/kg) and calcium (54 mg/kg) p.o. restored BMD by 31, 46 and 32 %, respectively, compared with negative control group. Leek extract also reduced the ethanol-induced elevation in serum alkaline phosphatase and malondialdehyde levels. It was concluded that protective effect of leek alcoholic extract on osteoporosis in rats may be attributed to its antioxidant capacity.

Anti-inflammatory and Gastroprotective Activities

Steroidal saponins from bulbs of leek (3β,5α,6β,25*R*)-6-[(β-D-glucopyranosyl)oxy]-spirostan-3-yl*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-glucopyranosyl-(1→3)]-β-D-galactopyranoside and 3-[(*O*-β-D-glucopyranosyl-(1→3)-β-D-glucopyranosyl-(1→2)-*O*-[*O*-β-D-glucopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranosyl) oxy]-2,6-dihydroxy-(2α,3β,5α,6β,25*R*)-spirostane showed haemolytic effects in the in-vitro assays and demonstrated anti-inflammatory activity and gastroprotective property using in-vivo models (Adão et al. 2011a, b).

Antihypercholesterolemic/ Hypolipidemic Activity

Treatment of rabbits on a hypercholesterolemic diet with 250, 500 or 1,000 mg/kg of body weight of extract a hydroalcoholic extract of *A. porrum* bulbs decreased plasma total cholesterol in a dose-dependent manner (Movahedian et al. 2006). Changes in the distribution of cholesterol in HDL or LDL were found, and LDL cholesterol decreased significantly in all of the groups treated with *A. porrum* extract with respect to the hypercholesterolemic group.

Antidiabetic Activity

Administration of ethanolic extract of leek leaves significantly reduced the serum glucose in streptozotocin-induced diabetic mice, but not in healthy mice (Eydi et al. 2007). The ethanolic extract also increased serum insulin in diabetic mice. Chronic oral administration of leek extract to STZ diabetic rats for 4 weeks significantly reduced serum glucose, cholesterol and triglyceride levels compared to control diabetic rats (Roghani and Aghaie 2007a). The scientists also showed that streptozotocin diabetic rats exhibited a higher score of pain at both phases of the formalin test and leek treatment for 1 month ameliorated this, while sodium salicylate administration significantly reduced pain score only at chronic phase of the test (Roghani and Aghaie 2007b).

Allium sativum and *Allium porrum* inhibited significantly the active transport of D-glucose across rat enterocytes in the rat everted intestinal sac experiment (Belemkar et al. 2013). Increased concentrations of both at 2.2 and 5.0 mg/mL in the mucosal solution significantly decreased absorption as well as transport across the rat intestine. D-glucose absorption along with transport was significantly inhibited at 2.5 and 5 mg/mL of garlic and leek compared to the control experiment groups. *A. porrum* showed more potent action.

Immunomodulatory Activity

The pectic polysaccharides obtained from leek exhibited good immunostimulating properties (Kratchanova et al. 2008, 2010). The highest immunostimulating activity was shown by the water- and chelate-extractable polysaccharides, which were also characterised by a high polyuronic acid content and polysaccharides with molecular mass over 10^6 Da. The water-extractable pectic polysaccharide had higher molecular weight (10^6 Da) and homogeneity.

Despite the lack of antioxidant activity, the pectic polysaccharides of leek significantly decreased the production of reactive oxygen species (ROS) by human neutrophils (Nikolova et al. 2013). Polysaccharides isolated from alcohol-insoluble substances (AIS) of leek markedly activated RAW 264.7 macrophages for reactive nitrogen species production in a concentration-dependent manner. The polysaccharides extracted from AIS with water showed the ability to fix serum complement, especially through the alternative pathway. It was found that the polysaccharide exhibiting the highest complement-fixing effect was characterised by the highest content of uronic acids and the highest molecular weight. A new steroidal saponin 3β,5α,6β,25R)-3-{(*O*-β-D-glucopyranosyl-(1→3)-β-D-glucopyranosyl-(1→2)-*O*-[*O*-β-D-glucopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranosyl) oxy}-6-hydroxyspirostan-2-one isolated from leek bulbs exhibited haemolytic activity in the in-vitro assays and immunological adjuvant activity on the cellular immune response against ovalbumin antigen (Adão et al. 2012).

Nguansangiam et al. (2003) found that pre- and post-topical treatment of leek volatile oil could protect against trichothecene toxin-induced epidermal damage (epidermal desquamation and necrosis with oedema and inflammatory cells infiltration) in the mouse footpad rich in epidermal Langerhans cells. Langerhans cells had been reported to play a critical role in cutaneous immunological reactions (Weiss 1988).

Platelet Antiaggregation Activity

Flavonoids isolated as kaempferol aglycones from the bulbs of leek exhibited human platelet antiaggregation activity (Fattorusso et al. 2001).

Spasmolytic Activity

Studies showed that *Allium ampeloprasum* leaf hydroalcoholic extract could affect rat ileum motor activity by affecting beta adrenergic receptors and voltage-dependent calcium channels (Sedighi et al. 2012). Leek leaf extract (100, 200 and 400 mg/kg), in a dose-dependent manner, reduced ileum contractions induced by potassium chloride. The intervention of beta adrenergic receptor antagonist (propranolol, 1 M), opioid receptors (Narcan, 1 M) and nitric oxide synthase inhibitor (L-name, 100 M) in ileum showed that propranolol decreased the inhibitory effects of the extract on the contractions caused by potassium chloride significantly. Based on the results, leek leaf extract may be used to treat digestive problems.

Allergy Issues

A 26-year-old woman was presented with asthma and contact eczema on handling leek for 3 years (Cadot et al. 2001). Some months after having started this work, she began to complain of conjunctivitis, rhinitis, asthma and eczema on the hands. She could not remember having allergic reactions to any other vegetable than leek. The patch test with leek was positive. The peculiarity of the present case was that the patient did not show any sign of common inhalant allergies nor was there cross-reactivity with the closest botanically related vegetables, namely, onion and garlic. Another case of occupational rhinitis to leek was reported by Armentia et al. (2005).

Traditional Medicinal Uses

Leek bulb is regarded to be anthelmintic, antiasthmatic, anticholesterolemic, antiseptic, antispasmodic, cholagogue, diaphoretic, diuretic, expectorant, febrifuge, stimulant, stomachic, tonic and vasodilator (Grieve 1971; Holtom and Hylton 1979; Launert 1981; Lust 1974). The crushed bulb may be applied as a poultice to ease the pain of stings and insect bites.

Allium porrum is employed as an antiatherogenic remedy in traditional Iranian medicine (Movahedian et al. 2006). In traditional Iranian medicine, Persian leek is employed for constipation, asthma, haemoptysis, gout, obesity, haemorrhoids and headache and as a diuretic,

emmenagogue and aphrodisiac (Avicenna and Bakhtiar 2012). Seeds are used for chronic diarrhoea, freckle, vitiligo, neuralgia, haemorrhoids and as appetiser and aphrodisiac.

Other Uses

Allium ampeloprasum contain compounds with insecticidal and antifungal properties.

Allium porrum produced nonprotein sulfur amino acids derived from cysteine, i.e. alk(en)yl-cysteine sulfoxides precursors of volatile thiosulfinates and disulfides, as a defence mechanism against insect species including the specialist leek moth, *Acrolepiopsis assectella* (Dugravot et al. 2005). They found an increase in the production of sulfur compounds in both the sulfur precursor propylcysteine sulfoxide and volatile form, occurring only in association with intensive attacks by leek moths and not by the generalist moth, *Agrotis ipsilon*. The increase in sulfur precursors also led to an increase in the release of sulfur volatiles.

Antifungal N-feruloyl amides *N*-feruloyltyrosine and *N*-feruloyl-tyramine, isolated from *A. porrum* roots, showed antifungal activity towards *Fusarium culmorum* (Fattorusso et al. 1999). Cinnamic acid derivatives *N*-feruloyl-tyramine and *N*-caffeoyl tyramine, isolated form leek seeds and bulb, inhibited in-vitro growth of *Botrytis cinerea*, and *N*-feruloyl tyramine inhibited *Penicillium italicum* and *Aspergillus niger* at a low concentration (Sadeghi et al. 2013a). Persicosides A and B from leek bulbs were active in-vitro against the tested fungal phytopathogens, *Penicillium italicum*, *Aspergillus niger*, *Trichoderma harzianum* and *Botrytis cinerea*, highlighting the positive effect of the spirostane skeleton on the antifungal activity (Sadeghi et al. 2013b).

Comments

Allium ampeloprasum is a complex species. The allopolyploid origin of great headed garlic (GHG) *Allium iranicum* and *A. polyanthum* was confirmed. No signs of hybridisation in leek or kurrat were detected, but possible introgression events were identified in pearl onion and bulbous leek (Hirschegger et al. 2010). They also clarified the previous incorrect classification of cultivated forms within *A. ampeloprasum*, by showing that leek, kurrat, pearl onion and bulbous leek should be considered separately from GHG. Recent studies on the diversity of small and wild to large and cultivated *Allium ampeloprasum* found that domesticated *A. ampeloprasum* (great headed garlic, kurrat and leek) clustered consistently within the ampeloprasum group (Guenaoui et al. 2013). A high number of single point mutations (SNPs) was recorded over the ITS1-2 spacer sequence. Most of these SNPs were heterozygous only in great headed garlic. It was inferred that heterozygosity played the major role in promoting great headed garlic domestication. Thus, great headed garlic adaptation to horticultural conditions along with its yield trait sizes was mainly associated to heterozygosity rather than to polyploidy. Vegetative, floral and chromosome morphology studies by Mousavi et al. (2006) suggested the Persian leek to be a distinct subordinate group of *A. ampeloprasum*.

Selected References

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Allium cepa

Scientific Name

***Allium cepa* L.**

Synonyms

Allium angolense Baker, *Allium aobanum* Araki, *Allium ascalonicum* auct., *Allium ascalonicum* var. *condensum* Millán, *Allium ascalonicum* var. *fertile* Millán, *Allium ascalonicum* f. *rotterianum* Voss ex J. Becker, *Allium ascalonicum* var. *sterile* Millán, *Allium cepa* var. *aggregatum* G. Don, *Allium cepa* var. *anglicum* Alef., *Allium cepa* var. *argenteum* Alef., *Allium cepa* var. *bifolium* Alef., *Allium cepa* var. *crinides* Alef. *Allium cepa* var. *flandricum* Alef., *Allium cepa* var. *globosum* Alef., *Allium cepa* var. *hispanicum* Alef., *Allium cepa* var. *jamesii* Alef., *Allium cepa* var. *lisboanum* Alef., *Allium cepa* var. *luteum* Alef., *Allium cepa* var. *multiplicans* L.H. Bailey, *Allium cepa* var. *portanum* Alef., *Allium cepa* var. *praecox* Alef., *Allium cepa* var. *rosum* Alef., *Allium cepa* var. *sanguineum* Alef., *Allium cepa* var. *solaninum* Alef., *Allium cepa* var. *tripolitanum* Alef., *Allium cepa* var. *viviparum* (Metzg.) Alef., *Allium cepaeum* St.-Lag., *Allium commune* Noronha, *Allium cumaria* Buch.-Ham. ex Wall., *Allium esculentum* Salisb., *Allium napus* Pall. ex Kunth, *Allium nigritanum* A. Chev. (inval.), *Allium pauciflorum* Willd. ex Ledeb., *Allium salota* Dostál, *Ascalonicum sativum* P. Renault, *Cepa alba* P. Renault, *Cepa esculenta* Gray, *Cepa pallens* P. Renault, *Cepa rubra* P. Renault, *Cepa vulgaris* Garsault (inval.), *Kepa esculenta* Raf., *Porrum cepa* (L.) Rchb

Family

Amaryllidaceae

Common Names

For *Allium cepa* var. *cepa* (Common Onion Group) (Plates 1, 2, 3, 4, 5, 6, 7, 8 and 9)

Bombay Onion, Brown Onion, Bulb Onion, Common Onion, Onion

For *Allium cepa* var. *aggregatum* (Aggregatum group) (Plates 10, 11 and 12)

Shallot, Potato Onion, Multiplier Onion

Vernacular Names

***Allium cepa* var. *cepa* (Common Onion Group)**
Afrikaans: Ui
Albanian: Qepë
Amharic: Gäyy Šenkurt
Arabic: Bassal
Armenian: Soch
Azerbaijani: Sogan
Basque: Kipula, Tipula
Belarusian: Tsabulji Zepchatyi, Tsabulji Repchatui
Bosnian: Crni Luk, Crveni Luk, Ljetnji Luk, Luk, Sogan, Zvibel

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Plate 1 Common onion plant habit

Plate 4 Spanish onion red-skinned cultivar

Plate 2 Onion inflorescences

Plate 5 Onion yellow-skinned cultivar

Plate 3 Onion orange-skinned cultivar

Plate 6 Onion large, greyish-white-skinned cultivar

Plate 7 Small white onion with pseudostems and adventitious roots

Plate 10 Shallot onion plants

Plate 8 Elongated echalion onion

Plate 11 Cluster of shallot bulbs close view

Plate 9 Mild echalion onion close view

Plate 12 Harvested shallot bulbs

Breton: Ognon
Brunei: Bawang, Bawang Besar, Bawah Merah
Bulgarian: Luk
Burmese: Kyet-Thun, Kyet-Th-Wonini, Kyet Thun Ni
Catalan: Ceba, Ceba Blanca, Ceba D'Egipte, Ceballot, Cebes Blanques, Cebes, Cebes Trompades, Seba
Chechen: Xox
Chinese: Chhang-Thâu, Iû-Chhang, Cong Tou, Ts'oūng-T'êou, Ts'oūng-Tzè, Yang Cong, Yuan Bian Zhong
Croatian: Crni Luk, Crljenac, Crveni Luk, Črlenec, Luk, Sijanac
Czech: Cibule, Cibule Kuchyňská
Danish: Kepa-Løg, Lřg
Dutch: Ajuin, Ui
Estonian: Sibul
Finnish: Punasipuli, Ruokasipuli, Sipuli
French: Oignon
French Haiti: Zonyon (Creole)
Gaelic (***Irish***): Oinniún
Gaelic (***Scottish***): Uinnean
Galician: Cebola
Georgian: Khakhvi, Chachvi, Háhvi
German: Bolle, Gartenzwiebel, Küchenzwiebel, Sommerzwiebel, Speisezwiebel, Zwiebel, Zwiebellauch
Greek: Kremmy Di To Koino, Kremmy Di, Kremmydi
Hebrew: Bazal, Besalim
Hungarian: Hagyma, Vöröshagyma, Vörösjagyma
Icelandic: Höfuđlaukur, Rauolaukur
India: Piyaj, Piyaz, Ponoru (Assamese), Palandu, Piaaj, Pinaaj, Piyaj, Piaj, Pyanj (Bengali), Dungari, Dungli, Kando (Gujarati), Piaj, Piaz, Piyaz, Pyaj, Pyaaz (Hindi), Eerulli, Irulli, Nirulli, Neeruli, Neerulli, Ullaagedde (Kannada), Ulli (Malayalam), Kanda, Kandaa (Marathi), Purun, Purun Sen (Mizo), Peas, Piaja, Ulli (Oriya), Peyaz (Punjabi), Deerghapathra, Durghandh, Mahaakanda, Nripakanda, Nripapriya, Nripavhaya, Nripeshtha, Palaandu, Palandu, Raajapalaandu, Raajapriya, Raajeshtha, Raktakanda, Rakthakanda, Rochaka, Yavaneshttha (Sanskrit), Erangayam, Ira-Vengayam, Iravengaayam, Irulli, Periya Venkayam, Vella-Vengayam, Vengayam, Vengaayam Eerulli (Tamil), Neerulli, Nirulli, Vulli, Ulli, Gaddalu, Urigaddalu, Erragaddalu, Erra Ulligadda, Vulligaddalu, Vullipayalu (Telugu), Neerullikand (Tulu), Pyaaz (Urdu)
Indonesia: Bawang Bombaj, Bawang Timor (Malay), Brambang Bombaj (Javanese), Bawang Bungbaj, Bawang Lampung Bawang Selat, Bawang Timor (Sundanese), Bhabang Temor, Bhabang Cena (Madurese)
Italian: Cipolla
Japanese: Tamanegi, Tama Negi, Tamane
Kashmiri: Prān, Prāna-Bagāra
Khmer: Khtüm Barang
Korean: Dungulpha, Yangp'a
Kurdish: Pyāz
Laotian: Bwàx Fàlangx, Phak Bouo
Latvian: Sīpols
Lithuanian: Valgomasis Svoqūnas
Macedonian: Kokar, Običen Kromid
Malaysia: Bawang, Bawang Besar, Bawang Merah
Majorcan: Ceba, Seba
Nepal: Pyaz (Nepali), Chāp (Newar)
Niuean: Aniani
Norwegian: Kepalřk Kepaløk, Løk, Matløk, Rødløk, Vanlig Kepaløk
Papua New Guinea: Anian
Persian: Piyaaz
Philippines: Sibuyas (Bikol), Sibuyas (Bontok), Sibuyas, Si Bolyas (Ibanag), Sibuyas (Ifugao), Lasona, Sibulyas, Cebollas, Siboyas (Iloko), Sibuyas (Kapampangan), Sibúyas (Pangasinan) Sibuyas Bombay, Sibuyas, Sibuyas Buyas (Tagalog)
Polish: Cebula, Cebula Jadalna, Cebula Zwyczajna, Czosnek Cebula
Portuguese: Ceba, Cebola, Cebola Ordinaria, Cebolla
Romanian: Ceapă Ceaclama, Ceapa Cultivată, Pentrubulb
Russian: Luk Repčatyj, Louk Repčhatyi, Louk Zepchatnyi, Louk Repka
Serbian: Arpadžik, Crni Luk, Crni Lukac, Crvenac, Crveni Luk, Glavata Ljutika, Kapula, Kromid, Kromit, Kromiti Luk, Luk, Lukac, Mrki Luk, Sejana, Sijanac, Voćak
Slovak: Cibul'a Kychyňská
Slovenia: Čebula, Navadna Čebula

Somali: Basal
Sorbian: Cybula
Spanish: Ajo Porro, Cebolla, Cebolla Ajera, Cebolla Común, Cebolla De Alcalá La Real, Cebolla De Chinchón, Cebolla De Granada, Cebolla Macho, Cebolla De Madrid, Cebolla Matancera, Cebolla Murciana, Cebollas, Cebolleta, Cebolletas, Cebollón, Siemprevivas
Sri Lanka: Luku Loonu (Sinahla)
Swahili: Kitunguu, Kitunguu Maji
Swedish: Lök, Matlök, Vanlig Lök
Tajik: Piëz, Pioz
Thai: Hom Farang, Hom-Yai, Hom Huayai
Tibetan: Tsōn
Turkish: Soğan, Soğan
Turkmen: Sogan
Ukrainian: Cibulja
Uzbek: Piyoz, Piëz
Vietnamese: Cu Hành, Củ Hŕnh Tây, Hŕnh Tây
Welsh: Nionyn, Wniwn, Wynwyn
Yiddish: Tsibehleh, Tsibehleh
Zulu: U-Anyanisi

***Allium cepa* var. *aggregatum* (Aggregatum group, shallots)**
Afrikaans: Salot, Aanteelui
Albanian: Qepë Shalotë
Arabic: Bassal El Shallut
Belarusian: Tsabulja Shalot
Bulgarian: Šalot
Burmese: Kyet-Thun-U-Galay
Chinese: Chhang, Fen Cong, Fen Nie Yang Cong, Hu Cong, Hu Ts'ung, Xi Xiang Cong, Xiang Cong
Creole: Echalott, Echalot
Czech: Cibule Šalotka Množilka, Šalotka
Danish: Skalotteløg, Kartoffelløg
Dutch: Sjalot
Estonian: Šalott
Finnish: Ryvässipuli, Salotten Sipuli, Salottisipuli
French: Échalote, Oignon-Patate, Ail Stérile
Gaelic: Seallóid
German: Eschlauch
Greek: Kremmydi To Askoclonio
Hebrew: Shum Ashkelon
Hungarian: Mogyoróhogyma, Aslottahagyma
Icelandic: Skalotlaukur
India: Asomiya Piyaj (Assamese), Ghundhun (Bengali), Gandana (Hindu), Piaz (Urdu)
Indonesia: Bawang Acar, Bawang Merah (Malay), Brambang Abang, Brambang Bali, Brambang Kleci, Brambang Petak, Brambang Siyem (Javanese), Bhabang Mera, Bhabang Tangghulun (Madurese), Bawang Acar, Bawang Berem (Sundanese)
Italian: Scalogno
Japanese: Sharotto
Khmer: Khtüm Krâhââm
Kirghiz: Kyrk Muun Pijaz
Kiribati: Te Anian
Korean: Jjogpa
Laotian: Hoom Bwàx
Latvian: Dārza Sīpols, Sīpols Loki, Šalotes Sīpoli
Macedonian: Skalunka
Malaysia: Daun Bawang, Bawang Merah, Bawang Kecil
Maltese: Ix-Xalloti
Nepali: Pyaz
Norwegian: Sjalottløk, Potetlåk, Sjalottløk, Potetlåk
Papua New Guinea: Lip Anian (Tok Pisin)
Philippines: Ghundhun; Cebollas, Sibolyi No, Sibulyas (Bikol), Idaya (Bontok), Salaysay (Bukidnon), Lasona, Lansona (Cebuano), Amput An Dumalom, Danggu, Pumalapaggar Danggu (Ifugao), Lasona (Pangasinan), Sibuyas Talalog, Bawang-Pula, Lukyu, Sibuyas, Sibuyas-Tagalog (Tagalog)
Polish: Szalotka
Portuguese: Chalota, Cebolinha-De-Bubinhos, Cebolinha
Romanian: Ceapă Esalota
Russian: Luk-Šalot
Serbian: Kozjak
Slovak: Šarlotka
Slovenian: Šalotka, Šalotka
Spanish: Chalote, Escaluña, Ascalonia
Sri Lanka: Rathu Loonu; Rathu Loonu (Sinhala)
Swahili: Vitunguu Shaloti
Swedish: Scharlottenlök
Tajik: Pioz
Thai: Hom, Hom-Daeng, Hom-Lek
Turkish: Askalon, Yabani Sarmisak
Turkmen: Adaty Şogan
Ukrainian: Šalot
Vietnamese: Hành Tăm, Hành Hương
Welsh: Sibwn

Origin/Distribution

Common onion in known only in cultivation and is believed to have probably originated from wild *Allium* progenitors from Central Asia in the region comprising Afghanistan, Iran and Turkmenistan (Havey 1995). The cultivated form is often polyploid ($2n = 16$, 32, 54) and possibly of hybrid origin. It exists in numerous cultivars, a few of which form large bulbils in the umbel. The onion of commerce is widely cultivated as a biennial in North America, Europe and Asia.

The leading world producers of dry onions based on production figures are China 22,600,000 tonnes, India 16,308,990 tonnes, the United States 3,277, 460 tonnes, Iran 2,260,000 tonnes, Russian Federation 2,090,814 tonnes, Egypt 2,024,881 tonnes, Turkey 1,819,000 tonnes, Pakistan 1,692,300 tonnes, Nigeria 1,350,000 tonnes, Bangladesh 1,159,259 tonnes, Brazil 1,519,022 tonnes, Netherlands 1,353,000 tonnes, Mexico 1,238,602 tonnes, Myanmar 1,140,000 tonnes, Republic of Korea 1,195,737 tonnes, Spain 1,187,100 tonnes, Ukraine 1,141,300 tonnes and Japan 1,097,000 tonnes (FAO 2013).

Agroecology

Onion is a cool season biennial that is tolerant of frost. Optimum temperatures for growth and development are between 12.8 and 20 °C. Temperatures below 10 °C initiate bolting of the onion or flowering. However, optimum temperatures for seedling growth are much narrower, with 20–25 °C being most productive.

Edible Plant Parts and Uses

Onion bulb is used as vegetable, seasoning and flavouring. The bulb is eaten raw or cooked. Eaten raw, it can be sliced up and used in salads, sandwich fillings, etc.; it can be baked or boiled as a vegetable in its own right and is also commonly used as a flavouring in soups, stews and many other cooked dishes. Some cultivars have been selected for their smaller and often hotter bulbs, and these are used for making pickles or chutneys.

A large number of processed products are made from onion and garlic, and these find their way into a wide array of processed foods. Concentrated oils are produced from steam distillation of fresh onion and garlic, and these are used to deliver onion or garlic flavour to processed foods. Dehydrated products make up a sizable portion of the onion and garlic processing industry. The resultant dried flakes can be further ground into powder and mixed with salt and calcium stearate to produce onion or garlic salt. In a number of countries, particularly in Asia, pickled onion and garlic bulbs are consumed. These are produced in a fermentation process and then bottled in vinegar and salt to make a sour pickle or vinegar and sugar to make a sweet pickle.

The leaves are also raw or cooked. There are some cultivars that have been selected for their leaves and are used in salads while still young and actively growing – the bulb is much smaller than in other cultivars and is usually eaten with the leaves.

The flowers are eaten raw and used as a garnish on salads. The flowers are somewhat dry and are less pleasant than many other species. The seeds are sprouted and eaten and impart a delicious onion flavour.

Fortification of bread with onion skin supplements influenced protein digestibility (a reduction from 78.4 % for control breads to 55 % for breads with a 4 % supplement) (Swieca et al. 2013). The interaction of onion flavonoids with proteins affected antioxidant efficacy and protein digestibility, thus, affording multiple effects on food quality and pro-health properties of bread. Sensory evaluation studies showed that replacement of wheat flour in bread with up to 3 % onion skin powder gave satisfactory consumer acceptability (Gawlik-Dziki et al. 2013). The 2–3 % onion skin addition caused significant improvement of antioxidant abilities of the bread.

Vinegar was successfully produced from the juice of a red onion cultivar, Kurenai, by batch culture using yeast and *Acetobacter aceti* (Horiuchi et al. 1999). Nutritional analysis revealed that the potassium content of onion vinegar was extremely high, while the amount of sodium was lower than that in conventional vinegars. Also, the total amino acid and total organic acid contents of the onion vinegar were, respectively, 1.6–6.9 times and 3.5–11.5 times those in other kinds of vinegars.

Studies showed that onion brown skin and top–bottom could be potentially used as functional ingredient rich in dietary fibre, mainly in insoluble fraction, and in total phenolics and flavonoids, with high antioxidant activity (Benítez et al. 2011). Moreover, brown skin showed a high concentration of quercetin aglycone and calcium, and top–bottom showed high concentration of minerals. Outer scales could be used as source of flavonols, with good antioxidant activity and content of dietary fibre. However, inner scales could be an interesting source of fructans and alk(en)yl cysteine sulfoxides. Additionally, discarded onions (cvs Recas and Figueres) could be used as a good source of dietary fibre and cv Recas also as a source of phenolics compounds.

Ethanol could be produced from onion wastes by transforming the onion juice into onion liquor via alcoholic fermentation with the yeast *Saccharomyces cerevisiae* González-Sáiz et al. (2008a, b). The onion bioethanol produced could be later used as a favourable substrate for acetic fermentation into acetic acid and finally obtain onion vinegar. Processing of onion cv. 'Recas' onion wastes (residues and surpluses of onion) to obtain a paste (mixture content) and applying a mild pasteurisation were the best alternatives to obtain an interesting stabilised onion by-product with good antioxidant properties that could be used as a functional food ingredient (Roldán et al. 2008).

Studies suggested the potential good uses of the fresh leaves of Romanian *Allium* spp. (*Allium cepa* var. 'Diamant', *Allium cepa* var. 'Rubiniu' and *Allium ursinum*) as condiment, ingredient or preservative in the food industry (Gîtin et al. 2014).

Botany

A biennial herb with adventitious, fibrous roots (Plates 7 and 11) within a radius of 30 cm from the stem and in the top 30 cm of the soil (Plates 1 and 10). Real stem is very much reduced at the base of the plant, the pseudostem, if formed by the sheathing leaf bases. Leaves 3–8 alternate, distichous, glaucous produced from the broadening stem apex, leaf lamina cylindrical later becoming hollow, up to 50 cm long, apex acute. The bulb is comprised of concentric, enlarged fleshy leaf bases, also called scales, a short distance above the stem. The outer leaf base dries and becomes scaly, thin and variously coloured yellowish brown, orangey brown, purplish, red, greyish white or white forming the protective coat (Plates 3, 4, 5, 6, 7, 8 and 9) and the inner leaf bases thicken as the bulb develops. The mature bulb is depressed globose, ovoid or elongate, varying in size from cultivar to cultivar, 5–8 × 3–10 cm. In the case of the Aggregatum group (shallots), bulbs are formed in clusters of 3–28 cloves from the single mother bulb. Scape persistent, solitary, erect, fistulose, inflated below middle, 30–100 cm × 3–20 mm. Umbel persistent, erect, compact, to 500-flowered, globose (Plate 2), bulbils occasionally found; spathe bracts caducous, 2–3, 3–4-veined, ovate, apex acute to acuminate. Flowers stellate to campanulate to urceolate, 3–7 mm; tepals erect to more or less spreading, white to pink with greenish midveins, withering in fruit, margins entire, apex obtuse or acute, outer ovate, inner oblong; stamens exserted; anthers white; pollen white; ovary crestless; style linear, equalling stamens; stigma capitate, unlobed; pedicel 10–50 mm. Seed coat not known.

Nutritive/Medicinal Properties

Bulb Nutrients/Phytochemicals

Although rarely used specifically as a medicinal herb, the onion has a wide range of beneficial actions on the body. It had been reported to contain

many vitamins and minerals and is rich in sulfur amino acids, flavonoids and phytosterols. Onion had also been reported to contain a variety of secondary compounds, such as flavonols, anthocyanin pigments, sterols and saponins (Brewster 1994). The amino compounds identified in the phenol–water, *sec*-butanol–tert-butanol–methylethyl ketone–water and *sec*-butanol–tert-butanol–methylethyl ketone–water extracts of onion were glutathione, aspartic acid, cysteine, cystine, glutamic acid, serine, canavanine, asparagine, glycine, arginine, lysine, threonine, tyrosine, methionine sulfoxide, alanine, dihydro-alliine, S-methyl cysteine, tryptophan, methionine, valine, phenylalanine and mixed leucines (Kuon and Bernhard 1963). Suspected as present was α-L-glutamyl-S-[β-carboxy-n-propyl]-L-cysteinyl glycine. The more abundant amino acids were arginine, glutamic acid, phenylalanine, leucines, tyrosine, lysine and methionine sulfoxide. The following amino acids and γ-glutamyl peptides were isolated from onion: isomers of S-methyl-L-cysteine sulfoxide, γ-glutamyl-S-(prop-1-enyl) cysteine sulfoxide, S-(2-carboxypropyl)-glutathione, cycloalliin; isomers of S-propyl-L-cysteine sulfoxide, isomers of L-methionine sulfoxide, S-(prop-1-enyl)-L-cysteine sulfoxide, γ-glutamyl-S-methyl cysteine; aspartic acid, L-glutamyl-valine, asparagine, threonine, serine, γ-glutamyl–methionine, γ-glutamyl–isoleucine, glutamic acid, S-(2-carboxypropyl)-L-cysteine, citrulline; proline; S-methyl-cysteine; glycine and unknown, alanine, γ-glutamyl-phenylalanine, S-allylcysteine, valine, pipecolic acid, methionine, S-(prop-1-enyl)-cysteine, isoleucine, leucine, tyrosine, β-alanine, phenylalanine, γ-aminobutyric acid, ethanolamine, ammonia, lysine, histidine, tryptophan, arginine and several unknowns (Matikkala and Virtanen 1967).

The proximate value per 100 g edible portion of raw onions had been reported by USDA-ARS (2014) as water 89.11 g, energy 166 kJ (40 kcal), protein 1.10 g, fat 0.10 g, carbohydrate 9.34 g, total dietary fibre 1.7 g, total sugars 4.24 g, sucrose 0.99 g, glucose 1.97 g, fructose 1.29 g, ash 0.35 g, Ca 23 mg, Mg 10 mg, P 29 mg, K 146 mg, Fe 0.21 mg, Na 4 mg, Zn 0.17 mg, Cu 0.039 mg, Mn 0.129 mg, Se 0.5 µg, vitamin C (total ascorbic acid) 7.4 mg, thiamine 0.046 mg, riboflavin 0.027 mg, niacin 0.116 mg, pantothenic acid 0.123 mg, vitamin B-6 0.120 mg, total folate 19 µg, total choline 6.1 mg, betaine 0.1 mg, vitamin A 2 IU, β-carotene 1 µg, lutein + zeaxanthin 4 µg, vitamin E (α-tocopherol) 0.02 mg, vitamin K (phylloquinone) 0.4 µg, total saturated fatty acids 0.042 g, 14:0 (myristic acid) 0.004 g, 16:0 (palmitic acid) 0.034 g, 18:0 (stearic acid) 0.0034 g; total monounsaturated fatty acids 0.013 g, 18:1 undifferentiated (oleic acid) 0.013 g; total polyunsaturated fatty acids 0.017 g, 18:2 undifferentiated (linoleic acid) 0.013 g, 18:3 undifferentiated (linolenic acid) 0.004 g; phytosterols 15 mg, and amino acids – tryptophan 0.014 g, threonine 0.021 g, isoleucine 0.014 g, leucine 0.025 g, lysine 0.039 g, methionine 0.002 g, cystine 0.004 g, phenylalanine 0.025 g, tyrosine 0.014 g, valine 0.021 g, arginine 0.104 g, histidine 0.014 g, alanine 0.021, aspartic acid 0.091 g, glutamic acid 0.258 g, glycine 0.025 g, proline 0.012 g and serine 0.021 g.

Eighty per cent of the total lipids of *Allium cepa*, *Allium sativum* and *Allium porrum* were found to consist of four fatty acids: linoleic (46–53 %), palmitic (20–23 %), oleic (4–13 %) and α-linolenic acid (3–7 %) (Tsiaganis et al. 2006). In onion, 43 fatty acids were determined, 18 of that above 0.4 % and 4 above 2.5 %. Phospholipids consisted of a limited number of specific fatty acids, while neutral lipids contained a wide range including some unusual fatty acids. Yellow onion extract contained more organic acid and free sugar than those detected in the white and red onion extract (Shon et al. 2004).

Dry matter content (dry weight basis) in five white and seven red varieties of onion varied from 10.66 to 14.80 %, total water-soluble sugars 41.50–74.00 %, reducing sugars 12.00–22.25 %, nonreducing sugars 25–62 % and total phenols 1.75–2.95 g/100 g (Baja et al. 1980). The lachrymatory factor and pyruvic acid content ranged from 8.00–27.25 mg/100 g to 6.18–13.27 µmol/g, respectively, on a fresh wt basis, respectively. Red varieties contained a higher phenolic content than white varieties. Varieties with higher phenolic contents had greater amount of colouring matter in the dehydrated onions. Among the organic

acids (glutamic, oxalic, pyruvic, malic, tartaric, citric and fumaric), in onion cultivars (Texas, Guayonje, San Juan de la Rambla, Carrizal Alto, Carrizal Bajo and Masca), glutamic acid was the most abundant organic acid (325 mg/100 g) followed by citric acid (48.5 mg/100 g) and malic acid (43.6 mg/100 g) (Rodríguez Galdón et al. 2008b). The sweetest onions with respect to low content of pyruvate and high amount of fructose and glucose ranged in pyruvate content from 2.7 to 3.6 μmol/mL (Vågen and Slimestad 2008). These cultivars were juicy and contained low amounts of fructooligosaccharides (FOS) and total flavonols. The most pungent onions contained the highest amounts of FOS among the cultivars: 4.53, 3.80 and 5.81 g/100 g fresh weight (FW), respectively. They also had a high content of flavonols (86.6, 159.2 and 97.6 mg/100 g FW) and high dry weight content (14.6, 13.5 and 15.6 g/100 g). Excepting the lachrymatory factor (thiopropanal S-oxide), frozen onion compounds were similar compared to those of fresh onion sample in terms of thiosulfinates and zwiebelanes (Mondy et al. 2002). Conversely, the other transformed (freeze-dried, sterilised) samples lost most of the initially formed compounds and produced mainly disulfides and trisulfides corresponding to the degradation of thiosulfinates and zwiebelanes. These dramatic changes underpinned the very different flavours of these manufactured products compared to fresh material.

Freeze-drying process of fresh onion maintained the concentration of S-alk(en)yl-l-cysteine sulfoxides (ACSOs), organic acids, total sugars, total protein and minerals and significantly increased vitamin C concentration (Colina-Coca et al. 2014). Regarding high-pressure processing (HPP), the concentration of ACSOs, total sugars and vitamin C of fresh onion was preserved at the three HPP assayed (200, 400, 600 MPa for 5 minutes at 25 °C); however, for some organic acids and minerals, small decreases were found. In high-pressure-treated onion (especially for treatment at 400 MPa), freeze-drying retained the levels of the major organic acids, total sugars, total protein and minerals (Ca, Fe, Mg, K, Na, Zn, Mn and Se) and increased the content of ascorbic acid and total vitamin C. Extensive differences were detected between the sugar concentrations in onion species (Soininen et al. 2014). Yellow onion contained the highest and red onion the lowest amounts of amino acids. The main flavonol–glucosides were quercetin 3,4′-diglucoside and quercetin 4′-glucoside. In general, the levels of flavonols were higher in yellow onions than in red onions.

Invertase activity in onion bulb increased progressively after 8 weeks of storage to 0.084 and 0.092 nkatal/g fresh weight (FW) and then sharply to 0.29 and 0.35 nkatal/g FW at 20 °C and 10 °C, respectively, and remained high during 5 weeks of storage before declining abruptly to 0.039 and 0.041 nkatal/g and remained low during the last 8 weeks (Benkeblia et al. 2004). Glucose increased to 17.73 and 14.62 mg/g FW after 4 weeks at 20 °C and 10 °C, respectively, then decreased sharply between week 5 and week 7 to 4.13 and 4.91 mg/g FW, respectively, and remained rather stable ranging from 9 to 10 mg/g FW at both temperatures. Fructose showed a similar pattern. Between week 10 and week 24, fructose ranged from 5 to 6 mg/g FW and from 6 to 7 mg/g FW at 20 °C and 10 °C, respectively. Sucrose increased to 19.63 and 14.43 mg/g FW at 20 °C and 10 °C, respectively, decreased during 3 weeks and then increased randomly from 5.69 to 9.42 mg/g FW at 20 °C, but remained in a steady state at 10 °C at 5.03 mg/g FW. During the last 6 weeks, the sucrose content was higher at 20 °C than at 10 °C.

Fructans/Oligosaccharides

Fructan (polyfructosylsucrose) was reported to be an important storage carbohydrate in onions (Vijn et al. 1997). Fructooligosaccharides (degree of polymerisation (DP) 3–*c*. 11) were the only non-structural carbohydrates detected apart from glucose, fructose and sucrose in onions (Bacon 1957, 1959; di-Miniac 1970; Bose and Shirivastava 1961; Darbyshire and Henry 1978, 1981). No starch or members of the raffinose series of oligosaccharides were detected (Darbyshire and Henry 1978, 1981). Maximum carbohydrate concentration occurred in DP 5 for *A. cepa* bunching onion (Darbyshire and Henry 1981). The trisaccharides,

1^F-fructosylsucrose and 6^G-fructosylsucrose were found in *A. cepa*. *A. cepa* also contained fructan–fructan fructosyltransferases which transferred fructosyl residues from trisaccharide to form tetrasaccharide and sucrose as the major products (Darbyshire and Henry 1981). The distribution of fructooligosaccharides in onion leaf bases had been studied, and the fructooligosaccharide contents were found to be higher in younger (inner) than in older (outer) leaf bases (Bacon 1959; Darbyshire and Henry 1978). Bacon (1959) found low molecular weight fructans in onion with DP up to 5 and reported two trisaccharides: *O*-α-D-glucopyranosyl,(1→2)-*O*-β-D-fructofuranosyl-(1→2) β-fructofuranoside = 1^F-β-fructosylsucrose (1-kestose or 1-kestotriose) and *O*-β-D-fructofuranosyl-(2→6)-α-D-glucopyranosyl (1→2) β-D-fructofuranoside = 6^G-β-fructosylsucrose (neokestose or 6G-kestotriose), which were absent outer older leaf bases and increases to a peak in the inner younger leaf bases. Both were also reported in onion bulbs by Darbyshire and Henry (1978). Di Miniac (1970) reported a similar distribution of tri-tetra- and pentasaccharides (DPs 3, 4 and 5) except that DP 3 and DP 4 were present in outer leaf bases fructans up to DP 11 were reported from onion bulbs and up to DP 9 in individual onion leaf bases (Darbyshire and Henry 1978). Nine fructooligosaccharides were isolated from onion bulbs and identified as 1^F(1-ß-D-fructofüranosyl)$_3$ sucrose [1,1,1-kestopentaose]; 6^G(1-ß-D-fructofüranosyl)$_2$ sucrose [1,16G-kestopentaose] and 1^F(1-β-D-fructofüranosyl)$_m$-6^G(1-ß-D-fructofüranosyl)$_n$ sucrose $m=1$, $n=1$; $m=2$, $n=1$ and $m=1$, $n=2$ (Shiomi 1989). The fructosyltransferases purified were confirmed to be sucrose–sucrose 1^F-ß-D-fructosyltransferase [SST], 1^F(1-ß-D-fructosyl)$_n$sucrose–1^F(1-β-D-fructosyl)$_m$sucrose 6^G-ß-D-fructosyltransferase [6^G-FT] and 1 F(1-ß-D-fructosyl)$_n$sucrose–1^F(1-ß-D-fructosyl)$_m$ sucrose 1^F-ß-D-fructosyltransferase (1^F-FT). The following fructooligosaccharides: 1-kestose (1-kestotriose), neokestose (6G-kestotriose), raffinose, 6-kestose, nystose, 1^F and 6^G-di-β-fructosylsucrose; 6^G(1-β-fructosyl)$_3$sucrose from onion leaves on extraction were resolved from one another except for fructosylraffinose and fructosylstachyose; 1^F(1-β-fructosyl)$_2$-6^G-β-fructosylsucrose (1 and 1,6G-kestopentaose) and 1^F-β-fructosyl-6^G(1-β-fructosyl)$_2$sucrose; and 1^F-β-fructosyl-6^G(1-β-fructosyl)$_3$sucrose and 1^F(1-β-fructosyl)$_2$-6^G(1-β-fructosyl)$_2$sucrose (Shiomi et al. 1991).

Fructan–fructan 6G-fructosyltransferase (6G-FFT) was reported as a key enzyme in the formation of the inulin neoseries, a type of fructan found in onion and other liliaceous plants (Vijn et al. 1997). The accumulation of fructooligosaccharides and the activities of fructosyltransferase (sucrose–sucrose 1_F-fructosyltransferase (SST), 1_F-fructosyltransferase (1_F-FT) and 6_G-fructosyltransferase (6_G-FT)) in the bulbs of three onion cultivars were investigated from June to September 1993 (Shiomi et al. 1997). The total fructooligosaccharide content increased from June until August and then decreased in September, except in one cultivar. The levels of neokestose and its related tetrasaccharides (1_F, 6_G-di-β-D-fructofuranosyl sucrose and 6_G (1-β-D-fructofuranosyl)$_2$sucrose) were higher than those of 1-kestose and nystose throughout growth of onion bulb. The activities of fructosyltransferase(sucrose–sucrose 1_F-fructosyltransferase (SST), 1_F-fructosyltransferase (1_F-FT) and 6_G-fructosyltransferase (6_G-FT)) were high in June and July and then decreased; SST activity was very low in September. The activity ratios of 6_G-FT to 1_F-FT varied between 1.86 and 2.65 over the growth period. Two trisaccharides, three tetrasaccharides and four pentasaccharides were identified, together with a mixture of hexa- and heptasaccharides. All the saccharides produced from sucrose, 1-kestose or neokestose, by the crude enzyme prepared from onion bulbs were identical to the saccharides occurring naturally in onion bulbs. A fructosyltransferase that transfers the terminal (2→1)-β-linked D-fructosyl group of fructooligosaccharides (1^F (1-β-D-fructofuranosyl)$_n$ sucrose, n >/=1) to HO-6 of the glucosyl residue and HO-1 of the fructosyl residue of similar saccharides (1^F(1-β-D-fructofuranosyl)$_m$ sucrose, m >/=0) was purified from an onion bulb extract (Fujishima et al. 2005). The enzyme tentatively classified as fructan–fructan 6^G-fructosyltransferase (6G-FFT) was proposed to play an important

role in the synthesis of inulin and inulin neoseries fructooligosaccharides in onion bulbs.

Benkeblia et al. (2005) found the contents of trisaccharide (Tri), fructooligosaccharide (FOS) and total FOS of onion bulbs decreased abruptly during the first 8 weeks of storage; however, at 10 °C, contents of Tri, FOS (DP 3–12) and total FOS were lower than those at 20 °C. 1-fructo-exohydrolase (1-FEH) peaked sharply after 10 weeks and seemed to be triggered by a decrease in sucrose content. 1-kestose-hydrolysing (1-KH) increased during the first 8 weeks and remained stable during the last 8 weeks of the 24-week storage.

Onion and shallot (*Allium cepa*) were reported to exhibit wide variation in bulb fructan content (Yaguchi et al. 2008). It was found that concordance between chromosome 8 localisation of sucrose phosphate synthase and elevated leaf sucrose levels conditioned by high fructan alleles at the Frc locus in onion bulb suggested that the Frc locus on chromosome 8 may condition much of this variation.

Onion cell walls comprised a range of pectic polysaccharides with varying proportions of neutral side chains (Mankarios et al. 1980). It was found that (1,4′)-linked galactans and a substituted xyloglucan were probably major components. Exhaustive treatment of onion tissue with pectin lyase solubilised 89 % of the total uronides of onion cell wall pectic polysaccharides (Ishii 1982). The galacturonides released from the tissue were separated into three fractions (10.7, 5.3 and 84 %, in order of molecular weight (MW)). The low MW fraction was a mixture of oligogalacturonides. The intermediate MW fraction was a rhamnogalacturonan II type component which contained 3- and 3,4-linked rhamnose. Methylation analysis showed that the pectic polysaccharides of onion resembled those of potato tuber. Onion cell wall materials were found to be rich in uronic acid and glucose, with smaller quantities of arabinose, galactose and xylose (Ng et al. 2000). In the fleshy scales, the lower epidermis contained relatively more galactose-rich pectic polysaccharides, whereas the upper epidermis and the papery scales contained virtually no galactose. A small but significant amount of ferulic acid was found in the walls, predominantly in the thick cuticle of the lower epidermis of fleshy scales. Alkali-labile wall-bound flavonoids were also detected.

In fresh onions, the Grano de Oro variety had low contents of total fructans and fructooligosaccharide (FOS) but high levels of reducing sugars (Jaime et al. 2001). In the other varieties, Sturon, Hysam, Durco and Caribo fructans were the main carbohydrates, the lowest polymerised FOS being the major oligomer. Storage period caused in these important varieties increased levels of free fructose attributed to fructan hydrolysis. Varieties with >16 % dry matter or 15 % soluble solids contents could be stored for 6 months at 0 °C and 60–65 % relative humidity. Brown onion skin exhibited the highest total dietary fibre (TDF) content (65.8 %) on a dry matter basis, followed by top (48.5 %) and bottom (38.6 %) and insoluble dietary fibre (IDF) being the main fraction found (Jaime et al. 2002). The soluble dietary fibre (SDF)–IDF ratio decreased from inner to outer tissues. Brown onion skin and outer leaves by-products appeared to be the most suitable sources of dietary fibre (DF) that might be used in food product supplementation. Cellulose and pectic polysaccharides were the main components of onion DF in all tissues. An increase in the uronic acids/neutral sugars ratio from inner to outer tissues was found, suggesting that the galactan side chain possessed a DF solubilisation role.

Carrizal Bajo and Carrizal Alto onion cultivars presented the highest moisture content and lowest protein, fibre, sugars and total fructans contents (Rodríguez Galdón et al. 2009). In contrast, the Texas cultivar had the highest total and insoluble fibre and glucose contents, the Masca cultivar had the highest ash and protein contents, the Guayonje cultivar had the highest fructose and total sugar contents, and the San Juan de la Rambla had the highest Brix degree and total fructan contents. Significant differences in many of the parameters analysed were observed between the two seed origins for the Guayonje and San Juan de la Rambla cultivars. Onion-soluble nonstructural carbohydrates were reported to consist of fructose, glucose and sucrose plus

fructooligosaccharides (FOS) with degrees of polymerisation (DP) in the range of 3–19 (Downes and Terry 2010). They found that a methanol-based free mobile phase method for LC-ELSD quantification of fructooligosaccharides was more efficacious at extracting sugars and FOS from onion flesh, eluting significantly higher concentrations of glucose, kestose, nystose and DP5-DP8 than the ethanol-based method. The polysaccharide fraction extracted from onion bulbs contained a mixture of galactan with short-length sugar chains, pectic polysaccharides and evident content of proteinaceous material (Golovchenko et al. 2012). Galacturonan and rhamnogalacturonan were the main constituents of the linear regions of the sugar chains of the pectic polysaccharides. The ramified regions included rhamnogalacturonan I. The side chains of the ramified region contained mainly 1,4-linked β-D-galactopyranose residues and lesser content of 1,3-linked β-D-galactopyranose and 1,5-linked α-L-arabinofuranose residues. Furthermore, the proteinaceous material was found to be partly linked to the sugar chains. The polysaccharide fraction extracted from onion bulbs was found to decrease absorption of ovalbumin (OVA) to the blood from the gut lumen (Golovchenko et al. 2012). The serum OVA level was threefold lower in mice fed with OVA mixed with the onion pectins compared with the control group, which was administered with OVA alone.

Other Phytoproteins/Peptides

Gamma-glutamyl peptidase that cleaves γ-glutamyl peptides was found in sprouting onion (Matikkala and Virtanen 1965). Extracts of commercially frozen onion, although possessing considerable peroxidase and catalase activity, were devoid of strong flavour and of L-cysteine sulfoxide lyase activity, the enzyme considered to be responsible for the development of onion flavour (Schwimmer and Guadagni 1968). It was found that both odour and pyruvic acid may be produced via the same enzyme but that the odour was formed after the formation of pyruvic acid. From the data, it was calculated that the odour threshold value of some of the enzymatically produced odour-bearing constituents in onions may be less than one part per billion. An enzyme capable of liberating *p*-nitroaniline from γ-L-glutamyl *p*-nitroanilide was purified 800-fold from sprouted onions (Schwimmer and Austin 1971). The purified enzyme was a transpeptidase, whereas crude onion extract may, in addition, possess a true γ-glutamyl hydrolase. It was suggested that such enzymes may play a role in the disappearance of peptides in post-dormant onions and may be useful evoking the full flavour potential of onion.

Quantitative analysis of γ-glutamyl peptides in onion bulbs showed that γ-glutamyl *trans*-(+)-*S*-(1-propenyl)-L-cysteine sulfoxide (γ-glutamyl propenyl CSO) and *S*-2-carboxypropyl glutathione (2CPGTH) were absent prior to bulbing and then at bulbing accumulated to levels of 2.1 and 0.4 mg/g FW, respectively, that were maintained throughout storage (Lancaster and Shaw 1991). The hydrolytic enzyme γ-glutamyl transpeptidase exhibited minimal activity in a stored bulb, but during sprouting, activity increased ca fivefold. Levels of γ-glutamyl propenyl CSO and 2CPGTH decreased by 50 % to 0.94 and 0.14 mg/g FW. γ-Glutamyl transpeptidase that catalyses hydrolysis of γ-glutamyl linkages in γ-glutamyl peptides and transfer of the γ-glutamyl group to amino acids and peptides was purified from sprouting onion bulb (Shaw et al. 2005). It catalysed transpeptidation of methionine by the synthetic substrate γ-glutamyl-*p*-nitroanilide (GGPNA) and obtained N-terminal peptide sequence. This enzyme showed high affinity for glutathione and glutathione conjugates. The major onion γ-glutamyl peptide, γ-glutamyl *trans*-S-1-propenyl cysteine sulfoxide (GGPrCSO), exhibited uncompetitive inhibition of transpeptidation by GGPNA. This suggested GGPrCSO to be a poor glutamyl donor and therefore unlikely to be an in-vivo substrate for peptidase activity by this enzyme. From onion bulbs, a novel antifungal peptide, allicepin, with molecular weight of 10 K was isolated (Wang and Ng 2004). A plant growth bioregulator was isolated from onion bulb and determined to be a peptide of molecular weight of 4,036 Da comprising 18-C-terminal amino acid sequence of 18 residues (Kulikova et al. 2011). It inhibited seedling growth and development of some vegetables.

Phenolic Compounds/Flavonoids (Flavonols, Dihydroflavonols, Anthocyanins)

Onions had been reported as a major dietary source of flavonoids (principally flavonols and dihydroflavonols and anthocyanins) (Rhodes and Price 1996; Slimestead et al. 2007). Epidemiologic evidence had correlated diets rich in flavonoid compounds with a low risk of coronary heart disease. Hertog et al. (1992) found onion to be the richest source of flavonols among 28 vegetables and fruits studied. Onions was described as one of the richest and most common source of the antioxidant flavonoid quercetin (Nemeth and Piskula 2007). The main flavonoids of onion extract were kaempferol, myricetin, quercetin and quercitrin (Hur et al. 2013). Yellow onions were found to contain 270–1,187 mg of flavonols per kilogram of fresh weight (FW), whereas red onions contain 415–1,917 mg of flavonols per kilogram of FW (Slimestead et al. 2007). At least 25 different flavonols had been characterised, and quercetin derivatives were the most important ones in all onion cultivars, while analogous derivatives of kaempferol and isorhamnetin had been identified as minor pigments. Onion peels contained abundant epicatechin and morin; their contents in the methanol extract were 1.1–4.8 times higher than those of in ethanol or acetone extracts. Other phenolics found included catechin, epigallocatechin gallate, quercitrin, myricetin, resveratrol, quercetin, naringenin, apigenin and kaempferol (Kim et al. 2013).

A general increase in the total sum of flavonoids was determined in onions during 7 months storage at ambient temperature, whereas fluctuations were observed in different onion fleshy scale layers (Sharma et al. 2013). The outer fleshy scales contain higher water content and also highest concentration of flavonoids per dry weight. Quercetin recorded increases during the storage period, and in each scale layer, the content of quercetin 3,4′-*O*-diglucoside was higher than quercetin 4′-*O*-monoglucoside, and these ratios were maintained during the storage period. The dry matter content increased towards the inner scales of onion. High content of glucose and fructose in the middle scales was observed, whereas high content of sucrose was found in the inner scales. The contents of sugars (fructose, glucose, sucrose) in onion bulb as a whole declined after 7 months. During storage, the distribution of amino acids (phenylalanine and tryptophan) varied inconsistently in different scale layers.

Herrmann (1956, 1958) identified quercetin 4-glucoside (spiraeoside) as the main flavonol and quercetin in the pigmented scales of ‘Braunschweiger Dunkelblutrote’ cultivar. Koeppen and Van Der Spuy (1961) identified quercetin 4′-glucoside as the main flavonol and also detected the presence of quercetin 5-glucoside and quercetin 3-diglucoside in the cultivar ‘Australian Brown’. Southport Yellow Globe, Southport White Globe and Southport Red Globe onion cultivars were found to contain quercetin 4′-glucoside, quercetin 3,4′-diglucoside, quercetin 4′,7-diglucoside and quercetin 3-glucoside (Brandwein 1965). In addition, Southport Yellow Globe contained quercetin, and Southport Red Globe contained quercetin and peonidin-3-arabinoside. Harborne (1965) found 3,4′-diglucoside and 7,4′ diglucoside of quercetin in onion. Starke and Herrmann (1975) found that onion scales contained exclusively glucosides of quercetin as flavonols, while the dry outer skins contained quercetin mainly in the free state. The flavonol concentration decreased from the outer to the inner scales, with higher levels in the outer than in the inner epidermis. Tissut (1972) identified quercetin 3-glucoside (isoquercetin), kaempferol 3-glucoside (astragalin), kaempferol 4′-glucoside and isorhamnetin 4′glucoside as minor pigments. Panisset and Tisot (1983) identified 3,7′-diglucoside, from onion bulb, quercetin 7-glucoside, kaempferol and kaempferol 7,4′-diglucoside as minor pigments. Kaempferol was detected in onion peels (Bhandari 1970). Fluorescing compounds in onion guard and epidermal cells were identified to be 7-*O*-glucuronides of quercetin and kaempferol (Weissenböck et al. 1987). In addition to the main flavonol glycoside spiraeoside in onion bulbs, kaempferol 4′-*O*-β-glucoside was found in

smaller amounts and traces of other flavonoids were also detected (Scheer and Wichtl 1987).

Four flavonol glycosides isolated from the wet scales of the deep purple onion cv. Res Creole were identified as quercetin 3′-glucoside, quercetin 4′-glucoside, quercetin 3,4′-diglucoside and isorhamnetin 3-glucoside (Omidiji 1993). Flavonoids in edible part of onion were isolated, and their structures were determined as quercetin 3-*O*-β-glucoside, quercetin 4′-*O*-β-glucoside, quercetin 7-*O*-β-glucoside, quercetin 3,4′-di*O*-β-glucoside and quercetin 3,7-di*O*-β-glucoside with the small amounts of quercetin 7,4′-di*O*-β-glucoside (Tsushida and Suzuki 1995). Kaempferol 3-β-glucoside, kaempferol 7-*O*-R-glucoside and kaempferol 3,7-di*O*-β-glucoside were obtained. The major flavonoid found in onion was quercetin 4′-*O*-β-glucoside, closely followed by quercetin 3,4′-di*O*-β-glucoside; these two flavonols accounted for more than 85 % of the total amount of flavonoids in onion. The flavonoid comprising more than 1 % of total flavonoid in onion were quercetin 3-*O*-β-glucoside, quercetin 7-*O*-β-glucoside, quercetin 7,4′-di*O*-β-glucoside and isorhamnetin 4′-*O*-*β*-glucoside. The minor flavonoids, isorhamnetin 3,4′-di*O*-β-glucoside, kaempferol 3,4′-di*O*-β-glucoside and kaempferol 4′-*O*-β-glucoside, were also detected in onion.

Total quercetin content in 75 yellow, pink and red onion cultivars varied from 54 to 286 mg/kg (Patil et al. 1995). White onions contained trace amounts of total quercetin. Free quercetin content in all the onions was low (<0.4 mg/kg) except in cultivar '20,272-G' (12.5 mg/kg fresh weight). Onion bulbs stored at 5, 24 and 30 °C, and controlled atmosphere (CA) for 0,1,2,3,4 and 5 months showed a most marked change in total quercetin content at 24 °C compared to other treatments, with a rise in mid-storage followed by a drop. Storage at 5 and 30 °C also demonstrated a similar change. Two major components, quercetin monoglucoside and quercetin diglucoside, account for 80 % of the total flavonoids in onions (Rhodes and Price 1996). Anthocyanins are only minor components of the flavonoid spectrum in the edible portion of red varieties. Seven major flavonoid compounds in onions were isolated and identified as quercetin, quercetin monoglucoside, quercetin diglucoside, isorhamnetin, isorhamnetin glycoside, rutin and kaempferol (Park and Lee 1996). Two flavonol–glucosides, quercetin 3,4′-*O*-diglucoside (Qdg) and quercetin 4′-*O*-monoglucoside (Qmg), accounted for over 85 % of the total flavonoids in three varieties of onion with Qdg as the main component (Price and Rhodes 1997). Quercetin was detected in these long stored onions but only at low levels of less than 2 % of the total. The remaining flavonoid fraction (approx. 15 %) comprised up to 17 different components of which quercetin 3-*O*-glucoside and isorhamnetin glucoside were prominent members although each contributes less than 1 % of the total flavonoid fraction. There were significant differences in the levels of Qdg and Qmg between the four different onion varieties analysed, Qdg varying from 50 to 1,300 mg kg^{-1} fresh onion tissue and Qmg from 36 to 394 mg/kg. Maceration of the tissue for the three varieties tested led to a loss of Qdg and the appearance of Qmg and free quercetin. Hirota et al. (1998) reported that the two major onion flavonol glycosides, quercetin 3,4′-*O*-diglucoside and quercetin 4′-*O*-monoglucoside, and a flavonol aglycone quercetin were mainly localised in the abaxial epidermis of scales. Their contents increased on aging. Peroxidase in scales oxidised flavonols in the order quercetin >> quercetin 4′-*O*-monoglucoside > isoquercetin >> quercetin 3,4′-*O*-diglucoside 1, and the activity was higher in the outer than in the inner scales. Contents of quercetin 3,4′-*O*-diglucoside and quercetin 4′-*O*-monoglucoside in scales were decreased by cooking by boiling. Quercetin 3,7,4′-*O*-β-triglucopyranoside together with quercetin, quercetin 4′-*O*-β-glucopyranoside and quercetin 3,4′-*O*-β-diglucopyranoside was isolated from the pigmented scales of *Allium cepa* var. 'Red Baron' (Fossen et al. 1998). Minor amount of taxifolin 4′-*O*-β-glucopyranoiside, a rare dihydroflavonol, was also detected. A new compound named quercetin 3′-methoxy-4′-*O*-β-D-glucopyranoside, together with three known compounds kaempferol, quercetin 4′-*O*-β-D-glucopyranoside and quercetin 3,4′-di-*O*-β-D-glucopyranoside(IV), were isolated from *A. cepa* var. *aggregatum* bulbs (Yang et al. 2000).

Three major flavonoids, kaempferol, myricetin and quercetin, were identified and quantified in Georgia-grown Vidalia onions (Sellapan and Akoh 2002). Quercetin was the major flavonoid (7.70–46.32 mg/100 g fresh weight, FW) present in all varieties, followed by myricetin (2.77–4.13 mg/100 g FW). Minor quantities of kaempferol (1.10–1.98 mg/100 g FW) were also detected. The flavonols extracted from 12 onion varieties (red, yellow, white) consisted mainly of quercetin and isorhamnetin in the form of aglycones and glycosides (Marotti and Piccaglia 2002). The highest amount of free quercetin was detected in the fresh bulbs of 'Tropea rossa tonda' (557.8 mg/kg), whereas that of total flavonoids was found in 'Dorata Density' (979.1 mg/kg). The golden cultivar 'Castillo' resulted in the highest bulb and flavonoid yields (6.7 kg/m and 5.2 g/m, respectively). The main flavonol in two Portuguese onion regional varieties, Póvoa white and Póvoa red onions, was quercetin 4′-glucoside, representing 55.3 % in the red variety (35.43 mg/100 g FW) and 54.35 % in the white (3.94 mg/100 g FW) (Rodrigues et al. 2003). Total anthocyanin content in red variety (5.37/100 g FW) was higher than for white variety (3.94/100 g FW). Consequently, antioxidant activity was higher for the red variety. Concerning pungency, red variety was classified as sweet (4.69 μmol pyruvic acid/g FW) and white as very sweet (3.12 μmol pyruvic acid/g FW).

Furusawa et al. (2003) isolated four flavonoid compounds from brown onion scales: different quercetin dimers (1 and 2), quercetin and quercetin 4′-glucoside. Seven flavonols were identified in southern Italian red onion, quercetin 4′-glucoside and quercetin 3,4′-diglucoside being the most abundant components (Bonaccorsi et al. 2005). Five minor flavonols, quercetin 3-glucoside, quercetin 7,4′-diglucoside, quercetin 3,7,4′-triglucoside, isorhamnetin 4′-glucoside and isorhamnetin 3,4′-diglucoside, were also found. Traces of isorhamnetin 3-glucoside and free quercetin were also detected. Fisetin (3,7,3′,4′-tetrahydroxyflavone), a flavonol, was reported in onions (Adhami et al. 2012; Syed et al. 2013).

Kaempferol 3-*O*-β-D-glucopyranoside (astragalin) was isolated from onion husk (Muminov et al. 2006). Furusawa et al. (2002) isolated quercetin and quercetin 4′-*O*-β-D-glucoside together with novel isomeric quercetin dimmers, 1,3,11α-trihydroxy-9-(3,5,7-trihydroxy-4H-1-benzopyran-7-on-2-yl)-5α-(3,4-dihydroxyphenyl)-5,6,11-hexahydro-5,611-trioxanaphthacene-12-one (quercetin dimer) and [1,3,11α-trihydroxy-9-(3,5,7-trihydroxy-4H-1-benzopyran-7-on-2-yl)-5α-(3,4-dihydroxyphenyl)-5,6,11-hexahydro-5,6,11-trioxanaphthacene-12-one]-4′-*O*-β-D-glucopyranoside (4′-*O*-β-D-glucopyranoside of quercetin dimer) from onion. Ly et al. (2005) isolated the following flavonoid compounds from the methanol extract of dry outer scales of onion: protocatechuic acid (3,4-dihydroxybenzoic acid) [1]; 2-(3,4-dihydroxybenzoyl)-2,4,6-trihydroxy-3(2*H*)-benzofuranone [2]; quercetin 4′-*O*-β-D-glucopyranoside [3]; quercetin [5]; 4′-*O*-β-D-glucopyranoside of quercetin dimer, i.e. 1,3,11α-trihydroxy-9-(3,5,7-trihydroxy-4H-1-benzopyran-4-on-2yl)-5α-[4-(β-D-glucopyranosyloxy)-3-hydroxyphenyl]-5,6,11-hexahydro-5,611-trioxanaphthacene-12-one [**7**]; 1,3,11α-trihydroxy-9-(3,5,7-trihydroxy-4H-1-benzopyran-4-on-2yl)-5α-(3,4-dihydroxyphenyl)-5,6,11-hexahydro-5,611-trioxanaphthacene-12-one [**8**] and a stereoisomer of 1,3,11α-trihydroxy-9-(3,5,7-trihydroxy-4H-1-benzopyran-4-on-2yl)-5α-[4-(β-D-glucopyranosyloxy)-3-hydroxyphenyl]-5,6,11-hexahydro-5,611-trioxanaphthacene-12-one [9]. Compounds [4a] and [4b] were found to be isomers of quercetin and protocatechuic acid moieties, but their precise structures could not be determined. Compound [6] was assumed to be stereoisomers of2-[4-(β-D-glucopyransoyloxy)-3-hydroxyphenyl]-3,5,7-trihydroxy-9-[2-(3,4-dihydroxyphenyl)-2,3-dihydro-2,3-epoxy-5,7-dihydroxy-4H-1-benzopyrane-4-on-8-yl]-4-H-1-benzopyrane-4-one. Mohamad (2008) isolated a new flavonoid named alliuocide G, with the structure 1,3,9,11α-tetrahydroxy-5α-(3,4-dihydroxyphenyl)-5,11-dihydro-5,6,11-trioxanaphthacene-12-one, together with four known compounds: 2-(3,4-dihydroxybenzoyl)-2,4,6-trihydroxy-3(2H)-benzofuranone;1,3,11α-trihydroxy-9-(3,5,7-trihydroxy-4H-1-benzopyran-7-on-2-yl)-5α-(3,4-dihydroxyphenyl)-5,6,11-hexahydro-5,611-

trioxanaphthacene-12-one (quercetin dimer); luteolin-7-*O*-β-D-glucopyranoside and [1,3,11α-trihydroxy-9-(3,5,7-trihydroxy-4H-1-benzo pyran-7-on-2-yl)-5α-(3,4-dihydroxyphenyl)-5,6,11-hexahydro-5,6,11-trioxanaphthacene-12-one]-4′-*O*-β-D-glucopyranoside (4′-*O*-β-D-gluco pyranoside of quercetin dimer) from the ethyl acetate fraction of the dried outer onion scales.

High concentrations of quercetin, quercetin 4(I)-glucoside, taxifolin, taxifolin 7-glucoside and phenylalanine were isolated from Tropea red onion bulb (Correa et al. 2005). Five quercetin compounds (isoquercetin, quercetin diglucoside, quercetin monoglucoside 1, quercetin monoglucoside 2 and free quercetin) and kaempferol were identified and quantified from five traditional onion cultivars from Tenerife (Rodríguez Galdón et al. 2008a). Quercetin monoglucoside 1 and quercetin diglucoside were the major flavonoids accounting for 80 % of the total quercetin content. Microwave extraction of antioxidant flavonoids from onion offered important advantages like shorter extraction time (23 minutes), cleaner feature (no solvent or water used) and extraction of valuable onion crude juice retaining fresh organoleptic properties with higher phenolic content (58.29 mgGAE/gDW) at optimised power (500 W) (Zill-E-Huma et al. 2009). Microwave extraction afforded significant yield (81.5 %) with 41.9 % of flavonol contents, with better retention of remaining flavonoids (55.9 %) in residues of onions. Quercetin 3,4′-diglucoside (239.7 mg/100 gDW) and quercetin 4′-monoglucoside (82.55 mg/100 gDW) were found as the main flavonols. Minor quantities of quercetin aglycone (traces), quercetin 3-monoglucoside (4.22 mg/100 gDW) and kaempferol (3.99 mg/100 gDW) were also detected in microwave onion extracts.

Quercetin (Q), quercetin 3,4′-di-*O*-β-glucoside (Q3, 4′G), quercetin 3-*O*-β-glucoside (Q3G) and quercetin 4′-*O*-β-glucoside (Q4′G) were determined in onion bulbs by electrochemical methods (Zielińska et al. 2008a). Total quercetin ranged from 83 to 330 μg/g F.W. in six selected cultivars of long-day or short-day onions (Yoo et al. 2010). Quercetin 3,4′-diglycoside and quercetin 4′glycoside were the two major compounds and comprised approximately between 94 and 97 % of total quercetin in onions. Also present were quercetin 4,7′-diglycoside, quercetin 3-glycoside, isorhamnetin 4′glycoside and quercetin.

Four new quercetin-derived oxidation products , namely, 2-(3,4-dihydroxyphenyl)-4,6-dihydroxy-2-methoxybenzofuran-3-one;3-phloroglucinoyl-2,3-epoxyflavanone; 3-[3-(1-methylglyoxy late-2,4,6-trihydroxyphenyl)]-2,3-epoxyflavanone and 3-(quercetin-8-yl)-2,3-epoxyflavanone) and 2,5,7,3′,4′-pentahydroxy-3,4-flavandione; and lunularin-4-*O*-β-D-glucoside, were isolated from a water extract of onion skin, together with other known compounds: 2,5,7,3′,4′-pentahydroxy-3,4-flavandione; β-sitosterol-3-*O*-β-D-glucopy ranoside; syringaresinol; quercetin and quercetin4′-*O*-β-glucopyranoside;4′-methylquercetin-3-*O*-β-glucopyranoside, 4′-*O*-methylquercetin and trihydroxyphenylglyxolate; methyl 2,4,6-trihydroxyp henylglyxolate; 4,2′3′-trihydroxybibenzyl; phloroglucinoyl-3,4-dihydroxybenzoate; methyl 3,4-dihydroxybenzoate; 3,4-dihydroxybenzoic acid; *p*-hydroxybenzoic acid and phloroglucinol (Ramos et al. 2006). Two known compounds, quercetin and quercetin 3′-*O*-β-D-glucopyranoside (Q3′G), and one novel compound, quercetin 3-*O*-β-D-glucopyranoside-(4→1)-β-D-glucopyranoside (Q3M), was identified in onion (Xue et al. 2011). These flavonoids were found to be more abundant in the onion peel than in the flesh or core. The major polyphenols detected in onion solid wastes were quercetin and quercetin 4′-*O*-glucoside, accompanied by protocatechuic acid and a benzofuranone derivative (Khiari and Makris 2012). It was found that quercetin 4′-*O*-glucoside content increased by 13.3 %, while quercetin, benzofuranone derivative and protocatechuic acid contents increased by 68.6, 37.5 and 58.4 %, respectively. β-Glycosidase activity exhibited fluctuations and increased by 38.2 %, whereas the peroxidase showed a constant increasing trend, leading in 21.7 % higher activity.

Lindahl et al. (2013) used a continuous flow hot water extraction and thermostable

β-glucosidase enzymatic hydrolysis (84 °C, 5 % ethanol, pH 5.5, 3 mL/minute) to extract quercetin from quercetin 3,4′-diglucoside in yellow, red and shallot onions and resulted in higher or similar yield (e.g. 8.4 μmol g(−1) fresh weight yellow onion) compared to a conventional batch extraction method using methanol as extraction solvent. Onion treated by high-pressure processing (HPP) and combined with freeze-drying and pulverisation (HPP-FD-P) increased quercetin 3,4′-diglucoside, quercetin 4′-glucoside, quercetin 3-glucoside and isorhamnetin 3,4′-diglucoside extractability (González-Peña et al. 2013). Eighteen compounds were identified in the volatile fraction of onion, belonging mainly to di- and trisulfides and aldehydes (Colina-coca et al. 2013). Freeze-dried and pulverised onion samples presented an increase in 2-methyl 2-pentenal, dimethyl trisulfide and methyl propyl trisulfide compared with diced samples regardless of the high-pressure treatment (Colina-coca et al. 2013). However, freeze-drying and pulverisation processes affected the stability of propionaldehyde, 1-propanethiol, hexanal, dipropyl disulfide and dipropyl trisulfide, diminishing their content regardless of high-pressure treatment. HP at 200 and 400 MPa/25 °C/5 minutes were the least detrimental treatments to the total fraction of volatile compounds, not affecting or even increasing the levels of some volatile compounds.

Main flavonoids (mg/kg FW) in the dry skin, outer fleshy layer, edible portion of Tropea red onions were, respectively, as follows: delphinidin 3-glucosylglucoside (3,524 mg, 47 mg, 65 mg), cyanidin 3-(6″-malonylglucoside) (330 mg, 100 mg, 15 mg), cyanidin 3-(6″-malonyl-3″-glucosylglucoside) (2,054 mg, 50 mg, 10 mg) and quercetin 4′-glucoside (1,887 mg, 656 mg, 598 mg) (Gennaro et al. 2002). Flavonols quercetin and quercetin derivatives were the major flavonols in Tropea red onion with quercetin 4-glucoside as the major compound. The anthocyanins were heavily concentrated in the skin and outer fleshy layer. The dry skin was found to be rich in anthocyanins and flavonols with a high percentage of aglycone forms. Anthocyanins comprised about 63 % of the dry skin. The outer fleshy layer was found to be rich in cyanidin derivatives. Major anthocyanins in Tropea red onions were delphinidin 3-(glucosylglucoside) and cyanidin 3-(malonylglucoside); other anthocyanins found included cyanidin glucoside, cyanidin (glucosylglucoside), delphinidin glucosylglucoside, petunidin (glucosylglucoside), cyanidin (malonylglucoside), cyanidin (malonyl glucosylglucoside), delphinidin 3-glucoside, petunidin glucoside, delphinidin and cyanidin aglycones. Storage of onions for 6 weeks in different conditions, all of them mimicking home storage habits, resulted in a decrease to 64–73 % of total anthocyanins. The same trend was verified for the total antioxidant activity, which was reduced to 29–36 %. A decrease in glucose and fructose content correlated with anthocyanin degradation was also observed. Storage at low temperature appeared to better preserve the onion anthocyanins.

Altogether at least 25 different anthocyanins had been reported from red onions, including two novel 5-carboxypyranocyanidin derivatives (Slimestead et al. 2007). The quantitative content of anthocyanins in some red onion cultivars had been reported to be approximately 10 % of the total flavonoid content or 39–240 mg/kg FW. The anthocyanins of red onions were mainly cyanidin glucosides acylated with malonic acid or nonacylated. Seven cyanidin and one peonidin glycosides were found in the bulbs of the Ruby and Southport Red Globe varieties of red onion; the major ones were cyanidin 3-glucoside and cyanidin 3-diglucoside (Fuleki 1971). The peonidin monoside present only in minor quantity was identified as peonidin 3-glucoside. Cyanidin 3-laminariobioside was identified in Spanish red onion by Du et al. (1974). Four cyanidin-based anthocyanins were isolated from the red onion and identified as cyanidin 3-glucoside, cyanidin 3-malonylglucoside, cyanidin 3-laminaribioside and cyanidin 3-malonyllaminaribioside (Teraha et al. 1994). Anthocyanins cyanidin 3-glucoside, cyanidin3-arabinoside,cyanidin3-malonylglucoside and cyanidin 3-malonylarabinoside and the flavonoids quercetin 3,4′-diglucoside, quercetin 7,4′-diglucoside, quercetin 3-glucoside, dihydroquercetin 3-glucoside and isorhamnetin 4′-glucoside

were identified in the edible parts of the Spanish red onion (cultivar 'Morada de Amposta') (Ferreres et al. 1996). The amount of anthocyanins reached 233 mg/kg and that of the flavonoids 943 mg/kg fresh weight of onions. The stability of the individual anthocyanins in onions after 7 days of storage at 8 °C was very different, the malonated anthocyanins being much more stable than the corresponding nonacylated pigments. Additionally, the arabinosides were shown to be less stable than the corresponding glucosides. Fossen et al. (1996) found that in five different red onion cultivars, cyanidin 3-(6′-malonyl-3′-glucosylglucoside), cyanidin 3-(6′-malonylglucoside) and cyanidin 3-glucoside constituted >95 % of the total anthocyanins. The colour of red onions was found to be due primarily to anthocyanins present in the epidermal cells of the scale leaves of the bulb (Donner et al. 1997). The occurrence of the four major anthocyanins, cyanidin 3-glucoside, cyanidin 3-laminaribioside, cyanidin 3-malonylglucoside and cyanidin 3-malonyllaminaribioside, was confirmed in four red onion cultivars, namely, 'Mambo', 'Red Jumbo', 'Red Bone' and 'Red Granex'. In addition, four new minor anthocyanin pigments including peonidin 3-glucoside and peonidin 3-malonylglucoside were isolated and characterised from red onions. Four anthocyanins with the same 4-substituted aglycone, carboxypyranocyanidin, were isolated from acidified, methanolic extracts of the edible scales and from the dry outer scales of red onion (Fossen and Andersen 2003). The structures of the two of them were identified as the 3-*O*-β-glucopyranoside (1) and 3-*O*-(6″-*O*-malonyl-β-glucopyranoside) of 5-carboxypyranocyanidin (2). The aglycone, 5-carboxy-2-(3,4-dihydroxyphenyl)-3,8-dihydroxy-pyrano[4,3,2-de]-1-benzopyrylium, was similar to carboxypyranomalvidin (vitisidin A) recently isolated from red wines with exception of the substitution pattern on the phenyl ring. Two analogues of compound 2 methylated at the terminal carboxyl group of the acyl moiety (compound 3) or at the aglycone carboxyl (compound 4), respectively, were also identified. The anthocyanins, cyanidin 3-*O*-(3″-*O*-β-glucopyranosyl-6″-*O*-malonyl-β-glucopyranoside)-4′-*O*-β-glucopyranoside,cyanidin7-*O*-(3″-*O*-β-glucopyranosyl-6″-*O*-malonyl-β-glucopyranoside)-4′-*O*-β-glucopyranoside, cyanidin 3,4′-di-*O*-β-glucopyranoside, cyanidin 4′-*O*-β-glucoside, peonidin 3-*O*-(6″-*O*-malonyl-β-glucopyranoside)-5-*O*-β-glucopyranoside and peonidin 3-*O*-(6″-*O*-malonyl-β-glucopyranoside) were isolated in minor amounts from pigmented scales of red onion (Fossen et al. 2003).

Inheritance studies indicated that a single gene determined the colour difference between yellow and red onions and that anthocyanin was a primary determinant of red colour in onions (Kim et al. 2004b). Of five structural genes, chalcone synthase (CHS), flavanone 3-hydroxylase (F3H), dihydroflavonol 4-reductase (DFR) and anthocyanidin synthase (ANS) genes, it was found that inactivation of DFR gene transcription resulted in blockage of anthocyanin production in yellow onions. Four anthocyanins were identified in red onion predominated by peonidin 3-glucoside and cyanidin 3-(6″-malonoyl-laminaribioside), while cyanidin 3-glucoside and cyanidin 3-(6″-malonoylglucoside) were found in lower amounts (Duangjit et al. 2014).

Microwave cooking without water better retained onion flavonoids quercetin 4′-*O*-β-glucoside (Q4′G) and quercetin 3,4′-*O*-β-diglucosides (Q3,4′G) and ascorbic acid (Ioku et al. 2001). Frying with oil or butter did not affect flavonoid intake. The boiling of onion led to about 30 % loss of quercetin glycosides, which were transferred to the boiling water. The hydrolysis of quercetin glycosides for daily cooking might occur with the addition of seasonings such as glutamic acid. Additional ferrous ions accelerated the loss of flavonoids. Commercial, dehydrated onion products contained low amounts or no flavonoids (Lee et al. 2008). Losses of onion flavonoids subjected to 'cooking' (in per cent) ranged as follows: frying, 33; sauteing, 21; boiling, 14–20; steaming, 14; microwaving, 4 and baking, 0. Small onions had higher flavonoid content per kilogram than large ones. There was a graduated decrease in the distribution of the flavonoids across an onion bulb from the first (outside) to the seventh (innermost) scale. Exposure to fluorescent light for 24 and 48 hours

induced time-dependent increases in the flavonoid content. Olsson et al. (2010) found that neither storage nor heat treatment caused any major differences in total flavonol content in sweet onion 'Recorra' and red onions 'Hyred' and 'Red Baron' cultivars. Quercetin 4′-glucoside did not show any consistent changes during storage in the two red cultivars, independent of treatment, whereas quercetin 3,4′-diglucoside increased significantly by 30 or 51 %, respectively, during storage in 'Hyred' and 'Red Baron' in the 24 hour heat treated onions. Isorhamnetin 4′-glucoside was present at two to three times higher amount in the sweet onion cultivar than in the two red cultivars. Some of the quercetin glucosides present at lower concentrations, isorhamnetin 3,4′-diglucoside, quercetin 3,7,4′-triglucoside and quercetin 7,4′-diglucoside, increased during storage in all treatments in both 'Hyred' and 'Red Baron', though sometimes a decrease was found at the end of the 8-month storage. Onion coproduct material from onion processing comprising the outer dried protective layer (outer paper layer) and first two fleshy leaf layers and onion press cake (material generated after juice extraction) was found to be potential commercial sources of flavonoids especially quercetin (Lee and Mitchell 2011). The first layer had significantly higher levels of flavonoids than the outer paper, second and inner flesh layers on a DW basis. The predominant forms of quercetin were the quercetin 3,4′-*O*-diglucoside and quercetin 4′-*O*-glucoside. Onion press cake had significantly higher levels of total quercetin as compared with fresh onions. The levels of quercetin 4′-*O*-glucoside significantly decreased during the first month of storage and remained stable for 12 months of storage at either 4 or 22 °C.

Quercetin 3,4′-*O*-diglucoside (3,4′-Qdg) and quercetin 4′-*O*-glucoside (4′-Qmg) comprised >80 % of the total flavonol content detected in the studied varieties using infrared spectroscopy (Lu et al. 2011). The method was found to have advantages over the traditional HPLC method in providing a valid, efficient and cost-effective method requiring less sample preparation for the quantification of quercetins in onion.

Volatiles and Sulfur Compounds

According to Block (1992), most of the nonprotein sulfur in *Alliums* could be found in the form of four principal ACSOs: methyl (MeCSO), 2-propenyl (2-PeCSO), 1-propenyl (1-PeCSO) and propenyl (PCSO). 1-PeCSO was found in the highest concentration in onions, and 2-PeCSO was found in the highest concentrations in garlic with only trace amounts in onions. Among three common *Allium* crops, the total ACSO concentration was generally highest in garlic, intermediate in onion and lowest in leek (Block 1992; Coley-Smith 1986). Of eight *Allium* species, garlic and giant garlic contained greatest amounts of total S-alk(en)yl-L-cysteine sulfoxides (ACSO) (5.0–11.7 mg/g); Chinese chive, dehydrator onion, leek, shallot had moderate amounts (2.0–5.0 mg/g), and Japanese bunching onion, onion (TG 1015Y) and chive leaves contained least amounts of total CSO (<2 mg/g) (Yoo and Pike 1998). AlCSO (S-allyl-L-cystine sulfoxide, alliin) was the major precursor in garlic and giant garlic (3.2–9.8 mg/g) and was also contained in chive and Chinese chive. PeCSO (S-propenyl-L-cysteine sulfoxide) was the main flavour precursor in onion, green onion, leek and shallot (0.3–2.2 mg/g) but also found in chive, Chinese chive, garlic and giant garlic. MeCSO (S-methyl-l-cysteine sulfoxide) was a major precursor in chive and Chinese chive (0.68–1.85 mg/g fresh wt.) and found in all eight species examined with less amounts. S-propyl CSO, however, was not found in any of these species. In onion, *S*-2-propenyl-L-cysteine sulfoxide (alliin; 2-PRENCSO) was found as the major sulfoxide (Fritsch and Keusgen 2006) which afforded propanethial *S*-oxide (lachrymatory factor [LF]), 1-propenyl methane thiosulfinate and dipropyl disulfide (Block et al. 1992; Rose et al. 2005).

Major volatile components detected in onion were 2-methyl-2-pentenal, (*E*)-methyl 1-propenyl disulfide, methyl propyl trisulfide and propanethiol, whereas dipropyl trisulfide, dipropyl disulfide and (*E*)-propenyl propyl disulfide predominated in leek oils (Schulz et al. 1998). According to the higher amount of leek chromosomes in the cell

nucleus, the percentages of the measured sulfur volatiles in the hybrid material corresponded more to the leek than to the onion flavour profile.

Niegisch and Stahl identified hydrogen sulfide, sulfur dioxide, acetaldehyde, propionaldehyde, methyl alcohol, n-propyl alcohol, *n*-propyl mercaptan and traces of *n*-propyl disulfide from onion (Niegisch and Stahl 1956). S-methylcysteine sulfoxide and S-*n*-propyl cysteine sulfoxide or dihydroalliin, from which the corresponding thiosulfinates were formed enzymatically, were isolated from Finnish onions (Virtanen and Matikkala 1959a). Methyl sulfide, methyl trisulfide, methyl-*n*-propyl disulfide, methyl-*n*-propyl trisulfide, n-propyl disulfide and *n*-propyl trisulfide were isolated and identified as important flavour components in onion (Carson and Wong 1961b). (+) S-methyl-L-cysteine sulfoxide and of (+) Sn-propyl-L-cysteine sulfoxide were isolated from onions as their N-2, 4-dinitrophenyl derivatives (Carson and Wong 1961a). Presence of thiothiamine was demonstrated in onion extract after adsorption on acid clay, fractional separation from filter paper pulp and paper chromatography (Suhara 1962). Existence of thiothiamine had been demonstrated in onion extract after adsorption on acid clay, fractional separation from filter paper pulp and paper chromatography (Suhara 1962). Existence of thiothiamine had been demonstrated in onion extract after adsorption on acid clay, fractional separation from filter paper pulp and paper chromatography (Suhara 1962). The precursor of the lachrymatory factor in onion was characterised as (+)-S-(prop-1-enyl) – L-cysteine sulfoxide which was cleaved by onion enzyme preparation to the lachrymatory factor (propenylsulfenic acid) – pyric acid and ammonia (Spare et al. 1963). Propenylsulfenic acid was very unstable and was spontaneously degraded to propionaldehyde from which some 2-methyl-2-pentenal was formed. In mild alkaline solution, the precursor of the lachrymatory factor, S-(propen-1-yl)-L-cysteine sulfoxide, was cyclised to the amino acid cycloalliin (3-methyl-1,4-thiazane-5-carboxylic acid-1-oxide) (Virtanen and Matikkala 1959b). The highest content of cycloalliin was found from onion imported from Hungary (3.2 g hydrochloride per kg), and from a batch of Finnish onions, 1.4 g/kg. was isolated. The amino acid S-(2-carboxypropyl)-cysteine and its sulfoxides were found to be precursors in the biosynthesis of cycloalliin (3-methyl-1,4-thiazane-5-carboxylic acid-1-oxide) in onion (Granroth and Virtanen 1967). A lachrymatory factor in onion was identified as thiopropanal S-oxide (Brodnitz and Pascale 1971). Lukes (1971) used thin-layer chromatography to determine the relative concentration of the lachrymator and other cysteine derivatives of the action of alliinase on the flavour precursor, S-propenyl-L-cysteine sulfoxide. The lachrymator factor (thiopropanal *S*-oxide) was extracted from onion juice by rapid spectrophotometric method and other flavour compounds identified from the action of alliinase (Freeman and Whenham 1975). Methyl propyl disulfide, methyl propyl trisulfide and dipropyl trisulfide with three under unidentified compounds were mainly responsible for the characteristic flavour of onion (Galletto and Bednarcyzk 1975). 2,5-Dimethylthiophenes, 2,4-dimethyl thiophene and 3,4-dimethyl thiophene were identified as onion volatile flavour components (Galetto and Hoffman 1976).

The principal disulfide present among the volatiles fresh 'Sunspice' onions was di-St-propyl, followed in descending order of concentration by n-propyl allyl, methyl-n-propyl, methyl allyl, dimethyl and diallyl disulfides (Bernhard 1968). In dehydrated onions, this order was markedly altered. Methyl-n-propyl is the principal disulfide, followed by dimethyl, methyl allyl, di-n-propyl, n-propyl allyl and diallyl disulfides. Loss of measured volatiles averaged 98 %, while loss of disulfides was greater than 89 %. The following aliphatic sulfur compounds were identified in the headspace volatiles of onions: di-n-propyl, n-propyl allyl, methyl-n-propyl, methyl allyl, dimethyl and diallyl sulfides (Bernhard 1969). These aliphatic disulfides appeared to be one of the principal groups of compounds responsible for the aroma and flavour of onions. 3,5-Dimethylthiophene, methyl *cis*-propenyl disulfide, methyl *trans*-propenyl disulfide, *cis*-propenyl disulfide, *trans*-propenyl propyl disulfide, two new methyl trisulfides and two propenyl trisulfides were found to be important

components in onion oil (Brodnitz 1969). The identification of 45 flavour constituents were identified in steam-distilled onion oil (Boelens et al. 1971). These several oxygen compounds are thiols, thiopenes, monosulfide, disulfides, trisulfide and tetrasulfide. Propyl thiosulfinates were found to be important in fresh onion flavour, propyl and propenyl disulfides and trisulfides in boiled onions and dimethylthiophenes, namely, 2,5-dimethylthiophenes, 2,4-dimethylthiophene and 3,4-dimethylthiophene in fried onions. The flavour precursor contents of short-day onion bulbs ranged from 0.03 to 0.16 mg/g fresh weight (FW) for S-methyl-L-cysteine-sulfoxide (MCSO), 0.07–0.65 mg for S-1-propenyl-L-cysteine sulfoxide (1-PeCSO) and 0.12–0.77 mg in total, and the precursor contents increased with the pungency levels (Lee et al. 2009). Onions of different pungency levels did not differ in the contents of individual or total free amino acids, and the most abundant amino acids were glutamine and arginine. The total sugar contents ranged from 50 to 75 mg/g FW, and total S contents (3.5–5.1 mg/g dry weight) were not correlated with the pungency levels. The study indicated onion pungency to be primarily determined by the content of flavour precursor compounds and not by total S, total sugars or individual/total free amino acids in short-day bulbs. Storage in controlled atmosphere maintained the quality of short-day onions best, as evidenced by the smallest changes in flavour precursors, pungency and sugar concentrations, while storage at 5 °C resulted in increased pungency (Yoo et al. 2012). Onion pungency levels significantly increased at 5 °C and decreased at 30 °C. For storage at 24 and 30 °C, fructose and glucose concentrations continuously decreased, accompanied by a continuous increase in sucrose concentrations.

A new volatile compound, 3, 4-dimethyl-2, 5-dioxo-2, 5-dihydrothiophene, was identified in onion together with methyldithiomethane; 2-methylbut-2-enal; 2-methylpent-2-enal; 1-(methyldithio) propane; 2,5-dimethylthiophene; 2,4-dimethylthiophene, 3,4-dimethylthiophene and 1-(propyldithio)propane; *cis*-1-(1-propenyldithio)propane, *trans*-1-(1-propenyldithio)propane; 1-(methyltrithio) propane and 1-(propyltrithio) propane (Albrand et al. 1980). In the case of onion, the processes of flavour development from n-propyl-L-cysteine sulfoxide (PCSO) and 1-propenyl-L-cysteine sulfoxide (PeCSO) were proposed (Yagami et al. 1980). The presence of propyl propanethiosulfinate, propanal and thiopropanal S-oxide was confirmed by isolation and identification of their sulfide derivatives. Propyl disulfide and 1-propenyl propyl disulfide (2 isomers 4) were detected as the main components of the characteristic onion flavour headspace. Other compounds identified included 2-methyl-2-pentenal, dimethylthiophenes (3 isomers) and propyl trisulfide. Cysteine derivatives of onion flavour intermediates found included cystine, lachrymatory factor derivative, cysteine, propanal derivative to 2-ethylthiazolidine-4-carboxylic acid and S-propyl-L-cysteine.

Sufur metabolism of onions, garlic and chives differed in some but not all respects from that in other plants (Granroth 1970). The cysteine formed was not stored but reacted further to give various S-substituted derivatives of which *trans*-(+)-S-(propen-L-yl)-L-cysteine sulfoxide (CSO) was the most efficiently accumulated, and this compound appeared to be the most important precursor of the flavour substances in onion, garlic and chive. 1-propenyl-L-cysteine sulfoxide (PeCSO) was the main flavour precursor in onion, green onion, leek and shallot (0.3–2.2 mg g^{-1}), but also found in chive, Chinese chive, garlic and giant garlic (Yoo and Pike 1998). *Trans*-(+)-S-(propen-l-yl)-L-cysteine sulfoxide (CSO) was also found to be important precursor of the flavour substances in onion, garlic and chive. *S*-methyl cysteine sulfoxide (MeCSO) was a major precursor in chive and Chinese chive (0.68–1.85 mg g^{-1} fresh wt.) and found in garlic, onion and leek in lesser amounts. Four non-volatile, odourless S-alk(en)yl cysteine sulfoxide (CSOs) were reported as the precursors of the flavour and odours of the *Allium* (Jones et al. 2004). These were *S*-methyl cysteine sulfoxide (MCSO, methiin; present in garlic, onion and other *Allium*), *S*-allylcysteine sulfoxide (ACSO, alliin; characteristic of garlic), *S-trans*-prop-1-enyl cysteine sulfoxide (PeCSO, isoalliin;

characteristic of onion) and *S*-propyl cysteine sulfoxide (PCSO, propiin; in onion, garlic and related species). The enzyme alliinase had been reported to cleave these precursors to give pyruvate, ammonia and a thiosulfinate. The lachrymatory effect, that is, characteristic of onions, was caused by the volatile product propanethial *S*-oxide (Brodnitz and Pascale 1971). The lachrymatory factor was reported to be generated by the activity of a second enzyme, lachrymatory factor synthase, following alliinase action on PeCSO, the major flavour precursor of onion (Imai et al. 2002). As well as CSOs, several γ-glutamyl peptide (γGP) derivatives of these flavour compounds had been detected within the *Allium* (Whitaker 1976). Over 17 types had been isolated (Granroth 1970) and including γ-glutamyl-*S*-alk(en)yl glutathiones, γ-glutamyl-*S*-alk(en)yl cysteines and γ-glutamyl-*S*-alk(en)yl cysteine sulfoxides, all proposed to derive from glutathione (γ-glutamyl cysteinyl glycine). However, they did not appear to contribute directly to flavour. Granroth (1970) confirmed that onion could hydrolyse *S*-2-carboxypropyl glutathione and that, in onion leaf tissue, *S*-2-carboxypropyl cysteine was rapidly converted to PeCSO. *S*-methyl cysteine, *S*-ethyl cysteine, *S*-propyl cysteine and *S*-propenyl cysteine could all be oxidised to the corresponding sulfoxide by onion leaf tissue (Granroth 1970). Methacrylate was proposed as the precursor of the allyl, propyl and propenyl groups (Granroth 1970). Glutathione and γ-glutamyl peptides were reported to be intermediates in the biosynthetic pathway to S-alk(en)yl-L-cysteine sulfoxides (flavour precursors) in *Allium sativum*, *A. cepa* and *A. siculum* (Lancaster and Shaw 1989). In all onion cultivars, the top and bottom onion sections contained the highest levels of both pyruvate and flavour precursors (alk(en)yl cysteine sulfoxides) with levels in the dry, brown skin being low or absent (Bacon et al. 1999). Significant increases in levels of both pyruvate and flavour precursors were observed in inner tissues and top/bottom sections after storage under commercial conditions.

S-alk(en)yl-L-cysteine sulfoxide (ACSO) flavour precursors concentration and composition of three onion cultivars changed with five sulfur fertility levels, and the response was cultivar dependent (Randle et al. 1995). At sulfur treatments that induced sulfur deficiency symptoms during active bulbing, (+)S-methyl-L-cysteine sulfoxide was the dominant flavour precursor, and the flavour pathway was a strong sink for available sufur. As sulfur fertility increased to luxuriant levels, *trans*(+)-*S*-(1-propenyl)-L-cysteine sulfoxide (PRENCSO) became the dominant ACSO. (+)S-propyl-L-cysteine sulfoxide was found in low concentration relative to total ACSO at all sulfur fertility levels. With low sulfur fertility, sulfur rapidly was metabolised, and low gamma-glutamyl peptide (gamma-GP) intermediates concentrations were detected. As sulfur fertility increased, gamma-GP increased, especially gamma-L-glutamyl-S-(1-propenyl)-L-cysteine sulfoxide, the penultimate compound leading to ACSO synthesis. Intermediates eluted were in the following sequence: (1) γ−L-glutamyl-L-glutamic acid, (2) aspartic acid, (3) 2-carboxypropyl glutathione, (4) γ−glutamyl-1-propenyl-L-cysteine sulfoxide, (5) (+)-S-methyl-l-cysteine sulfoxide (MCSO), (6) S-methyl glutathione, (7) γ−L-glutamyl-L-methionine, (8) *trans*(+)-S-(L-propenyl)-L-cysteine sulfoxide (PRENCSO), (9) γ− glutamyl-L-phenylalanine, (10) (+)-S-propyl-L-cysteine sulfoxide (PCSO), (11) butyl-L-cysteine sulfoxide and (12) butyl-l-cysteine sulfoxide. Nearly 95 % of the total bulb sulfur could be accounted for in the measured sulfur compounds at low sulfur fertility. However, at the highest sulfur treatment, only 40 % of the total bulb sulfur could be attributed to the ACSO and gamma-GP, indicating that other sulfur compounds were significant sulfur reservoirs in onions. Concentrations of enzymatically produced pyruvic acid were most closely related to PRENCSO concentrations. Onion bulbs accumulated significant levels of SO_4^{-2} and S (Randle et al. 1999). The amount of bulb-SO_4^{-2} and bulb-S increased linearly as S-fertility increased. The three varieties differed in total bulb-S, bulb-SO_4^{-2}, the per cent of total bulb-S accumulated as SO_4^{-2} and pyruvic acid. Bulb-SO_4^{-2} ranged from 0.047 to 0.318 % dry mass in response to S-fertility level and variety, while total bulb-S ranged from 0.154 to 0.535 % dry mass.

From the chloroform extract of onion juice, five partially new thiosulfinates and six hitherto unknown α-sulphinyldisulfides ('cepaenes') were isolated and their structures elucidated as *trans*- and *cis*-methylsulphinothioic acid *S*-1-propenyl ester; *cis*- and *trans*-*n*-propylsulphinothioic acid *S*-1-propenyl ester; *n*-propylsulphinothioic acid *S*-*n*-propyl ester and *trans*-5-ethyl-4,6,7-trithia-2-decene 4-*S*-oxide, *trans*, *trans* and *trans*, *cis* 5-ethyl-4,6,7-trithia-2,8-decadiene 4-*S*-oxide and the diastereoisomers of the latter three compounds (Bayer et al. 1989). Studies by Ferary et al (1996) found that *A. cepa* odours contained only thiopropanal *S*-oxide and thiosulfinates as sulfur volatiles. 3-Mercapto-2-methylpentan-1-ol, a powerful aroma compound, was isolated from raw onions (Widder et al. 2000). At low concentration (0.5 ppb), a pleasant meat broth, sweaty, onion and leek-like odour could be perceived. As one intermediate 3-mercapto-2-methylpentanal, another new strong flavour compound, was suggested. The amount of the potent onion odourant 3-mercapto-2-methylpentan-1-ol detected in raw onions ranged between 8 and 32 µg/kg, whereas 34 + 246 µg was found in sliced, stored (50 minutes) and then cooked onions(Granvogl et al. 2004). Highest concentration amounting to >1,200 µg/kg was obtained by simultaneous steam distillation.

Volatiles found in onion headspace were thiopropanal *S*-oxide, 2-methyl-2-pentenal, dimethyl thiophene, methyl propenyl disulfide, propenyl propyl disulfide, propenyl propenyl disulfide, dipropyl disulfide, 1-propenyl propyl disulfide, di-1-propenyl disulfide, methyl propyl trisulfide and traces of propenyl propenyl disulfide, dipropyl trisulfide and propenyl propyl trisulfide (Järvenpää et al. 1998). Among 49 identified components, in the steam distillate of onion,1-(methylthio)l-propanethiol;1-(propylthio)l-propanethiol; 5,6-dihydro-2-methyl-4,6-diethyl-4H-1,3,5-dithiazine; 5,6-dihydro-6-methyl-2,4-diethyl-4H-1,3,5-dithiazine; 5,6-dihydro-2,4,6-triethyl-4H-1,3,5-dithiazine and 2,4,6-triethyl-L,3,5-trithiane were reported in the oil of onion for the first time (Farkas et al. 1992). The other compounds included hydrogen sulfide; methane thiol; propanal; 1-propanethiol; *cis*-1-propenethiol; *trans*-1-propenethiol; 2-cyclopenten-1-one; 2-methyl-2-pentenal; 2,4-dimethylthiophene; 3,4-dimethylthiophene; *cis*-methyl 1-propenyl disulfide; *trans*-methyl 1-propenyl disulfide; methyl propyl disulfide; dimethyl trisulfide; dipropyl disulfide; *cis*-propyl 1-propenyl disulfide; *trans*-propyl 1-propenyl disulfide; methyl propyl trisulfide; *cis*-methyl 1-propenyl trisulfide; *trans*-methyl 1-propenyl trisulfide; isomer of 3,5-methylethyl-L,2,4-trithionale; isomer of 3,5-methylethyl-L, 2,4-trithionale; 4-ethyl-2,3,5-trithiahexane; 3,5-diethyl-1,2,4-trithiolane; dipropyl trisulfide; isomer of 3,5-diethyl-1,2,4-trithionale; isomer of 3,5-diethyl-1,2,4-trithionale; *cis*-propyl 1-propenyl trisulfide; *trans*-propyl 1-propenyl trisulfide; 5,6-dihydro-2-methyl-4,6-diethyl-4H-1,3,5-dithiazine;5,6-dihydro-6-methyl-2,4-diethyl-4H-1,3,5-dithiazine; isomer of 5,6-dihydro-6-methyl-2,4-diethyl-4H-1,3,5-dithiazine; 4-ethyl-2,3,5-trithiaoctane; 6-ethyl-4,5,7-trithia-octane; 4-ethyl-2,3,5-trithia-6-octane; isomer of 5,6-dihydro-2-methyl-4,6-diethyl-4H-1,3,5-dithiazine; isomer of 5,6-dihydro-2-methyl-4,6-diethyl-4H-1,3,5-dithiazine; dipropyl tetrasulfide; 6-ethyl-4,5,7-trithiadecane; 6-ethyl-4,5,7-trithia-2,8-decadiene; 4-ethyl-2,3,5,6-tetrathianonane; 6-ethyl-4,5,7,8-tetrathiaundecane;6-ethyl-4,5,7,8-tetrathia-trans-2-undecene; 6-ethyl-4,5,7,8-tetrathia-*cis*-2-undecene; 4-Pentyl-6-ethyl-L,2,3,5-tetrathiane and 5,7-diethyl-1,2,3,4,6-pentathiepane.

Forty-five compounds were identified in roasted onion volatiles from five different cultivars (Tokitomo 1995). Methyl propenyl trisulfide, diallyl trisulfide, methyl (*Z*)- and (*E*)-propenyl disulfides and furan compounds were the major aroma components of roasted onion, compared with those of boiled onion. Many aliphatic aldehydes existed in roasted onion volatiles. These volatile aldehydes were thermal generation and oxidation products from corn oil. Those aldehydes seemed to contribute to the characteristic oily and heavy roasted onion flavour. Twenty-four volatile compounds were identified in boiled onions; the major compounds were dipropyl trisulfide, diallyl disulfide, (*Z*)-propenyl propyl trisulfide, (*Z*)-propenyl

propyl disulfide; dipropyl disulfide and dimethyl trisulfide in decreasing amount (Tokitomo 1995). Other minor compounds included 2-methyl-2-pentenal, methyl propyl trisulfide, methyl (*Z*)-propenyl disulfide, methyl (*E*)-propenyl disulfide, (*E*)-propenyl propyl trisulfide, methanethiol, propanethiol, 2,4-dimethylthiophene, 3,4-dimethylthiophene, dibenzothiophene, 3-ethyl-5-vinyl-1,2,4-trithiolane (isomer), 3-ethyl-5-vinyl-1,2,4-trithiolane(isomer),3,4-dimethyl-2,5-dihydrothiophen-2-one, 6-ethyl-4,5,7-trithia-2,8-decadiene, *n*-hexanal, 2-pentylfuran, furfural and ethyl furyl ketone. Volatiles obtained from combined GC-MS analysis of garlic juice by solid-phase microextration (SPME) are the following: lachrymatory factor E and Z isomers, dimethyl thiosulfinate, dipropyl disulfide, propyl 1-propenyl disulfide, dipropenyl disulfide and dipropyl trisulfide, and obtained from solvent extraction are dimethyl thiosulfinate, methyl propyl thiosulfinate, methyl 1-propenyl thiosulfinate, propyl methyl thiosulfinate, 1-propenyl methyl thiosulfinate, dipropyl thiosulfinate, zwiebelane 1, zwiebelane 2, zwiebelane 3 and 1-propenyl propyl thiosulfinate (Mondy et al. 2001). In onion, 1-propenyl sulfenic acids rearrange to give mostly (*Z*, *E*) thiopropanal S-oxide, the lachrymatory factor and zwiebelanes isomers of di(1-propenyl) thiosulfinate.

Onionin A, a new, stable, sulfur-containing compound, was isolated from acetone extracts of onion bulbs, and its structure was characterised as 3,4-dimethyl-5-(1*E*-propenyl)-tetrahydrothiophen-2-sulfoxide-*S*-oxide (El-Aasr et al. 2010). The occurrence of the *S*-(+)-alk(en)ylthio-L-cysteine derivatives (*R*)-2-amino-3-(methyldisulfanyl) propanoic acid (*S*-methylthio-L-cysteine); (*R*)-2-amino-3-(propyldisulfanyl)propanoic acid (*S*-propylthio-l-cysteine); (*R*)-2-amino-3-(1-propenyldisulfanyl)propanoic acid (*S*-(1-propenylthio)-L-cysteine) and (*R*)-2-amino-3-(2-propenyldisulfanyl)propanoicacid(*S*-allylthio-L-cysteine) in onion was confirmed by Starkenmann et al. 2011. Their concentrations in fresh onion were estimated to be 0.19 mg/kg *S*-methylthio-L-cysteine, 0.01 mg/kg *S*-propylthio-L-cysteine and 0.56 mg/kg (*S*-(1-propenyllthio)-L-cysteine), concentrations that were about 3,000 times lower than that of isoalliin *S*-(1-propenyl-*S*-oxo-L-cysteine). These compounds were treated with *Fusobacterium nucleatum*, a microorganism responsible for the formation of mouth malodour. These L-cysteine disulfides were demonstrated to predominantly produce trisulfides and tetrasulfides. Isoalliin was almost entirely consumed by the plant enzyme alliin lyase (S-alk(en)yl-S-oxo-L-cysteine lyase) in a few seconds, but it was not transformed by *F. nucleatum*. Yoshinari et al. (2012) identified cycloalliin, S-methyl-L-cysteine, S-propyl-L-cysteine sulfoxide and dimethyl trisulfide in onions.

The total phenolic content determined in the crude onion extract was 11.3 mg phenols/g extract, the quercetin concentration was 27.5 μg/mL and propyl disulfide concentration was 0.23 μg/mL (Votto et al. 2010). Some of the sulfur compounds in crude onion extract were 1,3-dithiane, 2,2-dimethyl; 2-vinyl-1,3-dithiane; diallyl disulfide; 2,4-dimethylthiophene; 2-ethylidene[l,3] dithiane; [1,2,3,4]tetrathiine; 1-propene, 1-(methylthio)-,(*E*)-; 1-propene, 1-(methylthio)-,(*Z*)-; 5-methylthiophen-3-ylamine; thiophene; 2-ethyl-5-[(2-ethylbutyl)thio] and dimethyl tetrasulfide. Compounds belonging to other classes, such as phenols (phenol, 2,6-*bis*(1,1-dimethylethyl)-4-methyl) and carboxylic acids (1,2-benzenedicarboxylic acid, *bis*(2-methyl propyl) ester), were also identified. Seventeen organosulfides, including disulfides, trisulfides and cyclic polysulfides, were identified in shallot (*Allium cepa* Aggregatum group) (Tocmo et al. 2014). Significant differences in the quantitative and qualitative profiles of organosulfides in the hydrodistilled and solvent extracted oils were observed. Freeze-drying retained the majority of the organosulfides, but the whole-autoclaved and whole-boiled shallots lost more than 95 % of their organic polysulfides. Crushed-boiled and crushed-autoclaved shallot lost 76–80 % of their organosulfides, likely due to the thermal sensitivity of these compounds In general, disulfides increased at basic pH (pH 9.0), while trisulfides and cyclic organosulfides were much higher at the acidic to neutral pH values (pH 3.0–5.0).

In normal onion (*Allium cepa*), *trans*-*S*-1-propenyl-L-cysteine sulfoxide was transformed via 1-propenesulfenic acid into propanethial

S-oxide, a lachrymatory factor, through successive reactions catalysed by alliinase and lachrymatory factor synthase (LFS) (Aoyagi et al. 2011). Suppression of the LFS activity caused a dramatic increase in thiosulfinates previously reported as 'zwiebelane isomers'. After purification, they established the planar structure of the putative 'zwiebelane isomers' as *S*-3,4-dimethyl-5-hydroxythiolane-2-yl 1-propenethiosulfinate. Of at least three stereoisomers observed, one in the (2′*R*, 3′*R*, 4′*R*, 5′*R*)-configuration was collected as an isolated fraction, and the other isomers were collected as a combined fraction. Both fractions showed inhibitory activities against cyclooxygenase-1 and α-glucosidase in-vitro. After cutting onion, the headspace composition changed rapidly due to the very reactive volatile sulfurous compounds emitted from onion tissue after cell disruption (Løkke et al. 2012). It was found that propanethial *S*-oxide (the lachrymatory factor) and breakdown products of this compound dominated 0–10 minutes after cutting. Subsequently, propanethiol and dipropyl disulfide predominantly appeared, together with traces of thiosulfinates. The concentrations of these compounds reached a maximum at 60 minutes after cutting. Propanethiol was present in highest concentrations and had an odour activity value 20 times higher than dipropyl disulfide. Thus, propanethiol was suggested to be the main source of the characteristic onion odour. Minor amounts of hydrogen sulfide and methanethiol were also detected.

Twenty one compounds were identified in onion essential oil (Kocić-Tanackov et al. 2012). The major components were dimethyl trisulfide (16.64 %), methyl propyl-trisulfide (14.21 %), dietil-1,2,4-tritiolan (3*R*, 5*S*, 3*S*, 5*S* and 3*R*, 5*R* isomers) (13.71 %), methyl-(1-propenyl)-disulfide (13.14 %) and methyl-(1-propenyl)-trisulfide (13.02 %).

Garlic and onion, wild leek, had been reported to accumulate the selenium (Se) from soil, endowing the plants greater protection against carcinogenesis (Arnault and Auger 2006). Selenium level was found to be 0.024 μg/g for onion (Izgi et al. 2006). Selenomethionine, selenocysteine and Se-methyl-selenocysteine had been identified in garlic and onion (Yang 2002; Auger et al. 2004). Gamma-glutamyl-Se-methyl-L-selenocysteine had been identified in extracts of garlic cultivated in Se-rich soil (Auger et al. 2004). However, several Se compounds from Se-enriched garlic or onion remain unidentified (Arnault and Auger 2006). Se-methyl-selenocysteine was unstable in water extract of Se-enriched garlic when the extract was prepared and stored at room temperature (Yang 2002). Specific alliinase inhibitor hydroxylamine (NHOH.HCl) effectively prevented the loss of Se-methyl-selenocysteine, which suggested that the decomposition of Se-methyl-selenocysteine may be catalysed by alliinase. Se-enriched onion also contained alliinase and Se-methyl-selenocysteine, but its Se-methyl-selenocysteine was proved to be stable in the same water extract as that of Se-enriched garlic. The existence of Se-alk(en)yl-L-cysteine selenoxides (Se-'alliins') in garlic and onion had been demonstrated (Auger et al. 2004). An additional experiment showed that *Allium* species cultivated in Se-rich soil might contain two different Se-'alliins'.

Saponins and Other Phytochemicals

The saponins sitosterol, oleanolic acid and amyrin were found in onion (Smoczkiewicz et al. 1982). Steroid sapogenins isolated from onion included diosgenin (25R)-spriost-5-en-3β-ol; ruscogenin (25R)-spirost-5-ene-1β, 3β-diol and cepagenin (24S, 25R)-spirost-5-ene-1β,3β-24-triol and steroid glycosides ceposide A, ceposide B, alliospiroside A, alliospiroside B, alliospiroside C, alliospiroside D, alliofuroside A and ceposide D (Kravets et al. 1990). Four furostanol saponins, named tropeoside A1/A2 and tropeoside B1/B2, along with the respective 22-*O*-methyl derivatives (extraction artefacts), were isolated from Tropea red onion bulbs (Correa et al. 2005). High concentrations of ascalonicoside A1/A2 and ascalonicoside B were also found. Three saponins, named ceposide A, ceposide B and ceposide C, were isolated from the bulbs of white onion, and their structures elucidated as (25R)-furost-5(6)-en-1β,3β,22α,26-tetraol 1-*O*-β-D-xylopyranosyl 26-*O*-α-D-rhamnoyranosyl-(1→2)-*O*-β-D-

galactopyranoside (ceposide A), (25R)-furost-5(6)-en-1β,3β,22α,26-tetraol 1-*O*-β-D-xylopyranosyl 26-*O*-α-D-rhamnoyranosyl-(1→2)-*O*-β-D-glucopyranoside (ceposide B) and (25R)-furost-5(6)-en-1β,3β,22α,26-tetraol 1-*O*-β-D-galactopyranosyl 26-*O*-α-D-rhamnoyranosyl-(1→2)-*O*-β-D-galactopyranoside (ceposide C) (Lanzotti et al. 2011).

Pyruvic acid was detected in onion juice (Morgan 1946). Besides acetaldehyde and propionaldehyde, one unknown flavour compound of onion was identified as 2-methyl-2-pentenal which was formed enzymatically in crushed onions; the only alcohols detected were methanol and ethanol (Spare and Virtanen 1961). 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyranone (DDMP) was isolated from onions (Ban et al. 2007).

The following compounds with active quinone reductase inducing activity were isolated from *A. cepa*: *p*-hydroxyphenethyl *trans*-ferulate; 5,6-dimethyl-2-pyridinecarboxylic acid; ferulic acid; 1-(6-hydroxy-[3]pyridyl)-propan-1-one and N-*trans*-feruloyl 3-*O*-methyldopamine (Xiao and Parkin2006);5-hydroxy-3-methyl-4-propylsulfanyl-5H-furan-2-one; 5-(hydroxymethyl) furfural; acetovanillone; methyl 4-hydroxyl cinnamate and ferulic acid methyl ester (Xiao and Parkin 2006). Zwiebelane A (*cis*-2,3-dimethyl-5,6-dithiabicyclo[2.1.1]hexane 5-oxide) was reported from onion bulbs (Borjihan et al. 2010).

Onion bulbs were found to contain two volatile organic aliphatic methyl ketones 2-undecanone and 2-tridecanone (Antonoius 2013). Soil amended with chicken manure enhanced 2-undecanone and 2-tridecanone production by 28 and 43 %, respectively. The increased concentrations of 2-undecanone and 2-tridecanone in onion bulbs may provide a protective character against insect and spider mite attack in field-grown onions.

A fatty acid fraction separated from yellow onion corresponded for prostaglandin A1 (15-hydroxy-9-ketoprosta-10,13-dienoic acid or PGA_1) or a prostaglandin-like compound (Attrep et al. 1973). The following prostaglandins F1 alpha, E1, B1 and A2 were identified in onions (Al-Nagfy et al. 1986). Two isomeric trihydroxy octadecenoic acids, 9,10,13-trihydroxy-11-octadecenoic and 9,12,13-trihydroxy-10-octadecenoic acid, lipoxygenase metabolites of linoleic acid, with prostaglandin E-like activity were isolated from onion (Ustünes et al. 1985).

Seed Phytochemicals

Free radicals in onion seeds were found to be attributable to the melanins present in the black seed coats (Edwards et al. 1961). A new cysteine sulfoxide, (S(S)R(C))-S-(3-pentenyl)-L-cysteine sulfoxide, was identified from onion seeds, together with the known cysteine sulfoxides methiin, etiin, alliin, isoalliin, propiin and butiin (Dini et al. 2008). Four furostanol saponins, two of which were new compounds, named ceparoside A and ceparoside B, were isolated from onion seeds (Yuan et al. 2008b). Seven compounds tianshic acid, *N-trans*-feruloyl tyramine, β-sitosterol-3 β-glucopyranoside-6′-palmitate, sitosterol, daucosterol, tryptophane and adenine riboside were isolated from the ethanol extract of onion seeds (Yuan et al. 2008a). Two new steroidal saponins, ceparosides C and D, were isolated from onion seeds, and their structures established as 26-*O*-(β-D-glucopyranosyl)-(25R)-furost-5,20(22)-dien-3β,26-diol-3-*O*-β-D-glucopyranosyl-(1→4)-[α-L-rhamnopyranosyl (1→2)]-β-D-galactopyranoside (1) and 26-*O*-(β-D-glucopyranosyl)-(25S)-furost-5,20 (22)-dien-3β, 26-diol-3-*O*-β-D-glucopyranosyl-(1→4)-[α-l-rhamnopyranosyl(1→2)]-β-D-galactopyranoside (Yuan et al. 2009).

A sucrose–sucrose 1^F-β-D-fructosyltransferase was purified from onion seeds (Shiomi et al. 1985). The purified enzyme catalysed fructosyltransferase from sucrose to another sucrose to form 1-kestose and glucose and also in some degree transferred a fructosyl residue from sucrose to raffinose and stachyose but not to 1-kestose and nystose.

Root/Meristem/Cell Culture Phytochemicals

Changes in the activity of arginine decarboxylase and in polyamine content corresponded in time with growth activities of sprout meristems of onions (Matejko and Dalhem 1991). Alterations in the ratio of individual polyamines appeared to be an indicator of changes in the physiological state of onions during dormancy. Myosin was found to be localised to plasmodesmata in onion root tissues and may also play a role in the regulation of transport at the neck region of plasmodesmata (Radford and White 1998). Studies demonstrated that actin occurred not only in intact nuclei and chromosomes but also in DNA- and histone-depleted nuclei and chromosomes of *A. cepa* (Wan and Xing 1998). In addition, tropomyosin was found to be present in the nuclei and chromosomes of *A. cepa*. Sc II-like protein was found as a novel component in the nuclei, chromosomes and chromosome scaffolds of onion root meristematic cells (Wang et al. 2000). Spliceosomal proteins Sm and U2B were found in two nuclear domains: (1) a diffuse nucleoplasmic network similar to that formed by interchromatin granules and (2) numerous Cajal bodies in onion meristematic cells (Cui et al. 2003). Cruz et al. (2009) showed that actin isoforms with distinct solubilities were present in onion cell nuclei with a consistent subnuclear compartmentalisation. Actin and protein nuclear myosin 1 (NMI) were highly enriched in foci that were similar to transcription foci, although actin was also distributed diffusely in the nucleus and nucleolus as well as accumulating in a subset of the Cajal bodies. A water-soluble pectic polysaccharide (PS) was isolated from immature onion stick (Patra et al. 2013). It contained D-galactose, 6-*O*-Me-D-galactose, 3-*O*-acetyl-D-methyl galacturonate and D-methyl galacturonate in a molar ratio of nearly 1:1:1:1.

Lamins were detected in the nuclear matrix of *Allium cepa* meristematic root cells (Mínguez and de La Espina 1993). A nuclear coiled-coil structural protein NIF (nuclear intermediate filament) with molecular mass of 65kDA was found in the nuclear matrix of onion interacting directly with structural nuclear spectrin-like proteins (Pérez-Munive et al. 2012). Its similarities with some of the proteins described as onion lamin-like proteins suggested that they could be highly related or perhaps of the same proteins. Lamin-like protein analogues termed nuclear matrix constituent proteins (NMCP) which exhibited the typical tripartite structure of lamins were found in onion roots (Ciska et al. 2013). These proteins exhibited many similarities to lamins (structural organisation, conserved regions, subnuclear distribution and solubility) and that they may fulfil the functions of lamins in plants.

Exogenic application of O^{2-} and H_2O_2 generators resulted in formation of antimicrobial phytoalexins Tcibulins 1D and 2 in cultured onion cells (Kravchuk et al. 2003). Three major nucleolar proteins, nucleophosmin, nucleolin and fibrillarin, were found in onion root tip cells (Qin et al. 2013). A novel alliinase with two isoforms were purified from onion roots (Lancaster et al. 2000). Isoform I had an isoelectric point of 9.3, while isoform II had isoelectric points of 7.6, 7.9, 8.1 and 8.3. The isoforms differed in their glycosylation. Both contained xylose/fucose containing complex-type N-linked glycans, and isoform II also contained terminal mannose structures. Both isoforms had activity with S-alk(en)yl-L-cysteine sulfoxides. Unlike other *Allium* alliinases, onion root isoforms had cystine lyase activity.

Two major antifungal compounds purified from the n-butanol extract of shallot (*Allium cepa* Aggregatum group) basal plates and roots and were determined to be alliospiroside A and alliospiroside B (Teshima et al. 2013). Results of studies indicated that *A. cepa* plants were able to biotransform inorganic selenium compounds into their organic derivatives, e.g. Se-methyl-selenocysteine (SeMetSeCys) from the Se(IV) inorganic precursor (Michalska-Kacymirow et al. 2014). The content of selenium in onion roots (mg/kg dry mass) when plants were grown in the presence of selected Se

compounds were 670 mg Se when plants grown in sodium selenite (Na_2SeO_3); 979 mg Se when grown in sodium hydrogen selenite ($NaHSeO_3$); 2,700 mg Se when grown in sodium selenate ($Na_2SeO_4.10H_2O$) and 2,100 mg Se when in grown in sodium ammonium selenate ($NaNH_4SeO_4$). Organic derivatives found in onion roots of plant grown in sodium selenite and in sodium hydrogen selenite were selenomethionine-Se-oxide, SeMetSeCys, selenomethionine, Se(IV), L-γ-glutamyl-Se-methylseleno-l-cysteine (γ-glutamyl-SeMet-SeCys) and Se(VI). In contrast, roots of plants grown in sodium selenate and sodium ammonium selenate afforded Se (VI).

Leaf/Flower Phytochemicals

In the green leaves of onion, the flavonol synthesis was reported to be light dependent, and also kaempferol glucosides were formed beside quercetin glucosides, but not spiraeoside (quercetin 4′-glucoside) (quercetin 4′-glucoside) and the known diglucosides of the scales (Starke and Herrmann 1975). During drying on the field, an accumulation of flavonols takes place in the drying leaves. Fresh leaves of Romanian *Allium* spp. (*Allium cepa* var. 'Diamant', *Allium cepa* var. 'Rubiniu' and *Allium ursinum*) were found to be low pungent cultivars based on the enzymatically produced pyruvate level (between 42 and 222 μmol/g fresh weight) (Gîtin et al. 2014). Disulfides were detected as the major sulfur compounds, an allicin was found as an important sulfur compound.

Gołaszweska and Bednarska (1999) found that the cell walls of all mature anther tissues of onion mainly contained esterified pectins; only small amounts of unesterified pectins were present in the cell wall junctions and adjacent middle lamellae and in the cell walls of the connective tissue. Endogenous polyamines (PA) were reported to be involved in gametic embryogenesis in onions (Geoffriau et al. 2006). Spermidine in both free and conjugated forms was the most abundant PA quantitatively present in onion flower buds, accounting for 71–81 % of the total free PAs and 86–98 % of the total conjugated PAs. Free and conjugated putrescine put was detected in all varieties but was lower in concentration (maximum 0.36 μmol/g FW). Hydroxyputrescine was detected in some varieties but not the conjugated form. Spermin was found in lower concentration in one variety than in the other varieties, the conjugated form was not detected. Among the aromatic PAs, only tyramine and 3-hydroxy,4-methoxyphenylethylamine were detected. Free tyramine was found only in one ascension and also conjugated tyramine.

Antioxidant Activity

In-Vitro Studies

Garlic showed a higher DPPH free radical scavenging activity than red onion but had lower total phenolic content (37.60 mg GAE/100 g) than red onion (53.43 mg GAE/100 g) (Othman et al. 2011). However, the primary antioxidant activities of both were lower than the standard antioxidant, BHA. Red onion had higher ferrous ion-chelating effect (i.e. 45.00 %) as compared to garlic (43.29 %) but both showed slightly higher ion-chelating effect than BHA (tert-butyl-4-hydroxyanisole) (43.14 %) but lower than EDTA (ethylenediamine tetraacetic acid) (97.9 %). Among the 18 Korean onion cultivars, Sunpower was the most promising cultivar in terms of total phenolics, total flavonoids and antioxidant activity (Sharma et al. 2014). The antioxidant activity for cultivar Sunpower was highest in ethanol extracts 24.12 and 16.13 μM TE/g DW with FRAP and DPPH, respectively. Methanol extracts of cv Sunpower showed highest level of total phenolics (5,016 μg GAE/g DW) and flavonoids (2873.95 μg quercetin/g DW) among the 18 cultivars. Major phenolics in both methanol and ethanol extracts were quercetin, quercetin 3,4′-*O*-diglucoside(QDG),quercetin4′-*O*-monoglucoside (QMG) and isorhamnetin 3-glucoside. The total polyphenols and Trolox equivalent antioxidant capacity (TEAC) ranged from 73.33 to 180.84 mg/100 g FW and 0.92–1.56 μM TEAC/g FW, respectively, in Georgia-grown Vidalia onions (Sellapan and Akoh 2002). The data indicated *t* Vidalia onions were a rich source of quercetin,

and they also contained myricetin and kaempferol. A positive but weaker correlation was obtained for total polyphenols versus antioxidant capacity. Nevertheless, a stronger correlation ($R^2 = 0.34$) was obtained between flavonoid content versus antioxidant capacity. The scavenging activity of DPPH radical and H_2O_2 of red, yellow and white onion ethyl acetate extracts increased with increasing concentration (Shon et al. 2004). The antioxidant activities using β-carotene-linoleate system and reducing power also increased, but the effect was lower than that of BHT and ascorbic acid. The methanol extracts of onion and garlic extract gave similar antioxidant activity as determined by inhibition of lipid peroxidation induced by tert-butyl hydroperoxide in isolated rat hepatocytes and scavenging activity against DPPH radical (Nuutila et al. 2003). The radical scavenging activities also correlated positively with the total phenolics of the extracts. Onions had clearly higher radical scavenging activities than garlic, red onion being more active than yellow onion. The skin extracts of onion possessed the highest activities. The lowest levels of phenolics were detected for garlic (75–700 GAE mg/kg), whereas the highest amounts of phenolics were detected for the dry skin of onions: 80,000 GAE mg/kg in red and 26,000 GAE mg/kg in yellow onion. Intermediate levels were found in onion bulbs and stems (800–3,200 GAE mg/kg). Quercetin and kaempferol were found to be the most abundant flavonoids in the hydrolysed onion and garlic samples. The onion leaves contained mainly kaempferol, but quercetin was the major flavonoid in the other parts. The quercetin contents in the red onions were about twofold higher than those of the yellow onions, and, in the spring varieties, the differences were even bigger. Garlic did not contain quercetin or kaempferol in detectable amounts. The extracts of yellow onion were effective inhibitors of lipid peroxidation in rat hepatocytes, the dry skin again being the most effective. Concentrations of 10–80 mg/mL (based on the dry weight of the original extracted sample) resulted in 20–80 % lipid peroxidation inhibition. The edible part of onion was clearly less effective than the skin and a concentration of 1,000 mg/mL (dry weight of the original extracted sample) resulted in only 40 % lipid peroxidation inhibition. Garlic was a much less effective inhibitor of lipid peroxidation than yellow onion. However, according to Miller et al. (2000), garlic was found to be very high in antioxidants, its activity (1,300 Trolox equivalents/100 g) being about sixfold that of yellow onion (200 Trolox equivalents/100 g).

The total phenolic content (gallic acid, ferulic acid, protocatechuic acid, quercetin and kaempferol) of four (red, violet, white and green) onion varieties varied from 4.6 to 74.1 mg/g GAE, antioxidant activity varied from 13.6 to 84.1 % and free radical scavenging activity showed wide range in terms of IC_{50} (inhibitory concentration) from 0.1 to 15.2 mg/mL, EC_{50} (efficient concentration) from 4.3 to 660.8 mg/mg and antiradical power from 0.15 to 23.2 (Prakash et al. 2007). The outer dry layers of red and violet varieties showed better inhibition of lipid peroxidation assayed by ammonium thiocyanate than α-tocopherol. The non-site-specific inhibition of hydroxyl radical-induced deoxyribose degradation was also higher in the outer dry layers of red and violet varieties than in their middle and inner layers. The outer layers were also potential inhibitors of nitroblue tetrazolium chloride (NBT) reduction caused by superoxide anions. In contrast, the ferrous ion-chelating capacity of the red and violet varieties was highest in the inner layers. The unutilised outer layers of the red variety were a rich source of quercetin (5,110 μg/g) with high antioxidant (AOA) and free radical scavenging activities and also showed significant protection of DNA damage caused by free radicals.

The onion peel extracts by ethanol extraction showed greater DPPH radical scavenging activities and greater antioxidant activities as determined by ferric thiocyanate assay and lipid peroxidation inhibition than those by hot water extraction and subcritical water (SW) extraction at 165 °C. Antioxidant activity of onion peel extract by SW extraction at 110 °C was similar to that of ethanol extraction. Extraction yields of subcritical water (SW) extraction of antioxidant from onion peels were fourfold higher than ethanol extraction (Lee et al. 2014). However, the ethanol extraction increased total phenolic

contents (327.5 mg GAE/g extract) and flavonoid contents (183.95 mg QE/g extract) in the onion peel extract. In contrast, SW extract at 110 °C afforded 218.73 mg GAE/g extract of total phenolics and 119.50 mg quercetin/g extract; SW at 165 °C afforded 56.68 mg GAE/g extract GAE/g extract and 27.10 mg quercetin/g extract, and hot water (HW) extraction yielded 120.60 mg GAE/g extract total phenolic and 25.78 mg quercetin/g extract.

Nemeth and Piskula (2007) reported that the antioxidant quercetin (usually present in onions mainly as glycosides), even after being metabolised, may still affect the redox balance by inducing antioxidative and detoxifying enzymes or compounds which may be involved in sustaining homeostasis and confer beneficial effects to the human body. The flavonoid compounds especially quercetin and its dimerised compound isolated from onion skin having *o*-dihydroxy substituent in the B-ring were shown to be effective antioxidants against nonenzymatic lipid peroxidation (Ly et al. 2005). Compounds 5 and 8 had higher antioxidative activity compared to the corresponding glucoside (3 and 7). Four new quercetin-derived oxidation products isolated from onion skin, namely, 2-(3,4-dihydroxyphenyl)-4,6-dihydroxy-2-methoxybenzofuran-3-one; 3-phloroglucinoyl-2,3-epoxyflavanone; 3-[3-(1-methylglyoxylate-2,4,6-trihydroxyphenyl)]-2,3-epoxyflavanone and 3-(quercetin-8-yl)-2,3-epoxyflavanone); and 2,5,7,3′,4′-pentahydroxy-3,4-flavandione, were more active in scavenging DPPH free radical than quercetin (Ramos et al. 2006). Aqueous and hydroalcoholic extracts of raw were found to possess interesting antioxidant properties (DPPH scavenging, H_2O_2 scavenging and reducing power) which were significantly influenced by their chemical composition (Tătărîngă et al. 2008). Studies in a human digestion model showed that after digestion by the small intestine, the antioxidant activity values were dramatically increased, whereas the antioxidant activity was less influenced by digestion in the stomach for both onion extract and quercetin standard (Hur et al. 2013). The inhibitory effect of lipid oxidation of onion extract in mouse brain lipids increased after digestion in the stomach. The inhibitory effect of lipid oxidation of onion extract was higher in the high-fat-fed mouse brain lipids than that in the low-fat-fed mouse brain lipids. Thus, dietary onion may have important applications as a natural antioxidant agent in a high-fat diet.

The antioxidant and reducing activity of the dominant onion flavonoids quercetin (Q), quercetin 3-*O*-β-glucoside (Q3G), quercetin 4′-*O*-β-glucoside (Q4′G) and quercetin 3,4′-di-*O*-β-glucoside (Q3,4′G) in onion varieties Sochaczewska and Szalotka were determined by spectrophotometric (Trolox equivalent antioxidant capacity (TEAC), peroxyl radical trapping capacity (PRTC)) and cyclic voltammetry methods, respectively (Zielinska et al. 2008b). The dominant forms of quercetin in the onion var. Sochaczewska and Szalotka included Q4′G (61 and 54 %), Q3,4′G (37 and 44 %), Q3G (1.4 and 1.1 %) and free quercetin (1.1 and 0.7 %), respectively. The highest antioxidant capacity of onion was found under cumulative consideration of photochemiluminescence (water-soluble compounds + lipid-soluble compounds) and TEAC assays. The relative contribution of Q and its glucosides to the antioxidant capacity of onions showed a low contribution of Q, Q3G and Q3,4′G derived from CV, TEAC and PRTC assays, while the highest contribution to the antioxidant capacity of onions was provided by Q4′G.

Flavonoids were mainly present in ethyl acetate subfraction of three varieties of Spanish onions 34.92, 7.95, 0.38 μmol/g of rutin equivalent, and its antioxidant capacity was 74.86, 34.59 and 4.55 μmol/g Trolox (Santas et al. 2010). Red onion cultivars had the highest antioxidant activity as activity determined by both 'Ferric-reducing ability of plasma' (FRAP) and 'Trolox equivalent antioxidant capacity' (TEAC); 15.4 μmol TE/g DW for TEAC and 9.3 μmol TE/g DW for FRAP (Gokce et al. 2010). Yellow onions had higher TEAC (14.7 μmol TE/g DW) and FRAP value (9.8 μmol TE/g DW) than white onions (8.7 μmol TE/g DW) for TEAC and (5.6 μmol TE/g DW) for FRAP. Yellow onion group was found to have the highest total phenolic (TP) content (3.7 mg GAE/g DW), followed

by red onion (2.2 mg GAE/g DW) and then white onion (1.1 mg GAE/g DW) group. The values of TEAC and FRAP were significantly correlated by TP with similar Rs (0.74 and 0.73, respectively). TP, TEAC and FRAP were significantly and positively correlated to soluble solids (0.41, 0.43 and 0.40, respectively).

The ethyl acetate fraction of red onion peel was found to have high total phenolic content (384.7 mg GAE/g), total flavonoid content (165.2 mg QE/g), antioxidant activity (97.4 %), antiradical power (75.3) and reducing power (1.6 ASE/mL) (Singh et al. 2009). The ethyl acetate fraction had markedly higher antioxidant capacity than butylated hydroxytoluene (BHT) in preventive or scavenging capacities against $FeCl_3$-induced lipid peroxidation, protein fragmentation, hydroxyl (site-specific and non-site-specific), superoxide anion and nitric oxide radicals. The large amount of polyphenols (ferulic, gallic, protocatechuic acids, quercetin and kaempferol) contained in ethyl acetate fraction may cause its strong antioxidant and antimutagenic properties indicating that the ethyl acetate fraction of red onion peel may be used as natural antioxidant in nutraceutical preparations. Shim et al. (2011) found that the antioxidant activity (DPPH and Folin–Ciocalteu methods) of yellow and red onions was stronger in the outer layer than in the inner layer, and strong correlation was found between antioxidant activity and total phenolic content ($R^2 = 0.927$). Myricetin was the most bioaccessible among flavonoids in both red and yellow onions after digestion. The anthocyanin extract of outer and inner layers of white onion showed high free radical scavenging activities with $IC_{50} = 2.69 \times 10^{-5}$ and 5.89×10^{-5} mg/mL, respectively, exhibiting a tenfold higher antioxidant scavenging activity as compared with ascorbic acid (Benamalek et al. 2013). The outer layer of onion was rich in flavonols with contents of 103 μg/g DW (red variety) and 17.3 μg/gDW (white variety). The anthocyanin contents in the inner and outer layers of white onion were 0.045 mg/g and 0.077 mg/g, respectively.

The volatile sample of freeze-dried onion sprout (extracted with dichloromethane) inhibited hexanal oxidation for 40 days by >99 % at levels >100 μg/mL (Takahashi and Shibamoto 2008). Among the total of 71 components identified in the volatile sample, 24 were sulfur-containing compounds, which comprised 36.87 % of the total volatile chemicals identified. The volatile sample and water sample II exhibited moderate antioxidant activity in a malonaldehyde/gas chromatography assay and thiobarbituric acid assay, whereas water sample I did not show appreciable activity. It was found that blanching and frying and then microwaving of garlic and onions did not decrease significantly the amounts of their bioactive compounds (polyphenols, flavonoids, flavonols, anthocyanins, tannins and ascorbic acid) and the level of antioxidant activities (Gorinstein et al. 2008). The HPLC profiles of free and soluble ester- and glycoside-bound phenolic acids showed that *trans*-hydroxycinnamic acids (caffeic, *p*-coumaric, ferulic and sinapic) were as much as twice higher in garlic than in onions. Quercetin quantity was the highest in red onion among the studied vegetables. The electrophoretic separation of non-reduced garlic and onion proteins after boiling demonstrated their degradation in the range from 50 to 112 kDa.

High hydrostatic pressure (HHP) of 300 or 600 MPa/1–3 minutes/25 °C treatment of onions increased extracted phenolic content and antioxidant activity (Vázquez-Gutiérrez et al. 2013). HHP produced changes in membrane permeability and disruption of onion cell walls favouring the release of phenolic compounds from tissue and, in consequence, improving their extractability. Onion treated by high-pressure processing (HPP) and combined with freeze-drying and pulverisation (HPP-FD-P) increased quercetin 3,4′-diglucoside, quercetin 4′-glucoside, quercetin 3-glucoside and isorhamnetin 3,4′-diglucoside extractability (González-Peña et al. 2013). The results suggested that HPP (especially treatment at 400 MPa) and HPP-FD-P may be of benefit for obtaining functional ingredients from onion, as suggested by increased NO(•) scavenging capacity and maintenance of the antioxidant activity mainly in hydrolysed extracts.

The methanolic onion peel extract exhibited the highest oxygen radical absorbance capacity

(ORAC) values, which were 1.7- and 1.1-fold greater than those of acetonic and ethanolic extracts, respectively (Kim et al. 2013). The total phenolic contents, expressed as mg GAE/g of onion peel, ranged from 53.7 to 123.8 mg; they were highest in methanolic onion peel extract: 2.3- and 1.2-fold higher than those in acetone and ethanol extracts. ORAC was strongly correlated with total phenolic content ($R^2 = 0.980$). In the DPPH assay, all onion peel extracts (5–100 μg/mL) exhibited a dose–response effect. The half-maximal inhibitory concentrations on DPPH free radicals (IC_{50}) were as follows: methanolic extract (44.7) > ethanolic extract (41.7) > acetonic extract (39.3) In contrast to the total phenolic content, ORAC and DPPH assay results, total radical trapping antioxidant potential (TRAP) was highest in ethanol extract (EC_{50}= 86.9), which was 1.7- and 1.2-fold higher than those of methanolic and acetonic extracts, respectively. In HepG2 cells, onion peel extract at concentrations from 1 to 100 μg/mL reduced oxidative stress; 5 μg/mL extracts restored them to levels similar to that of the control group. In HepG2 cells, onion peel extract at concentrations from 1 to 100 μg/mL reduced oxidative stress; 5 μg/mL extracts restored them to levels similar to that of the control group.

The 60 °C water (mild heat) treatment of fresh-cut onion slices resulted in a significant increase in total phenolics from 44.92 to 52.32 mg GAE/100 g (Siddiq et al. 2013). Except for 50 and 70 °C treatments, total phenolics in control and 60 °C treated fresh-cut onions decreased during storage. The antioxidant properties of fresh-cut onions were 1.31, 0.99 and 62.49 μM TE/g using ABTS, DPPH and ORAC assays, respectively. The mild-heat treatments did not affect ABTS and DPPH antioxidant activities and the colour of fresh-cut onions. The storage time had mixed effect on the antioxidant properties (ABTS decreased; DPPH and ORAC remained fairly stable). The 50 °C samples exhibited the lowest weight loss during the 21-day storage.

The antioxidant activity of an onion seed extract containing cysteine sulfoxides was found to have reducing activity (FRAP) rather than DPPH radical scavenging effects (Dini et al. 2008). The new cysteine sulfoxide, (S(S)R(C))-S-(3-pentenyl)-L-cysteine sulfoxide, showed a low antioxidant activity, when compared with the standards used. Yellow onion extract showed enhanced antioxidative effects in 2,2-diphenyl-1-picrylhydrazyl (DPPH), Trolox equivalent antioxidant capacity (TEAC) and 5-(and-6)-chloromethyl-2′,7′-dichlorodihydrofluorescein diacetate and acetyl ester (CM-H(2)DCFDA) assay after being treated with a crude enzyme extract from soybean paste fungi, *Aspergillus kawachii* (Yang et al. 2012a). After enzyme treatment, contents of quercetin 3,4′-di-*O*-β-D-glucoside and quercetin 4′-*O*-β-D-glucoside decreased while that of quercetin 3-*O*-β-D-glucoside and quercetin increased. Among the increased compounds, only quercetin showed strong antioxidative activity in the DPPH assay.

All 31 shallot (*Allium cepa* var. *aggregatum*) strains derived from different regions of Vietnam and six other countries showed potent antioxidant activities in a DPPH assay (Vu et al. 2013). The highest antioxidant capacity was in the strains possessing relatively high contents of polyphenol, quercetin and saponin. Significant correlations were found between antioxidant capacity and four groups of chemical compounds (polyphenols, quercetins, saponins and S-alk(en)yl-L-cysteine sulfoxide (ACSO)). The phenolic content of skins from different coloured onions (pearl, red, yellow and white) was approximately six times higher than that of their fleshy edible parts (Albishi et al. 2013). Among onion varieties, pearl onion skin showed the highest phenolic content (26.4 mg quercetin eq./g freeze-dried sample). Quercetin 3,4′-diglucoside, quercetin and kaempferol were the predominant phenolics in all onion extracts tested. A similar trend was observed for free radical scavenging activity of the tested samples. Extracts from edible part of onion showed lower activity in all antioxidant tests carried out. Onion essential oil showed moderate antioxidant activities in ABTS assay (0.67 mg/mL as IC_{50} value), DPPH test (IC_{50} value = 0.63 mg/mL) and metal-chelating assay (IC_{50} value of 0.51 mg/mL) (Ye et al. 2013). Furthermore, the reducing power of the oil was dose dependent,

but was inferior to butylated hydroxytoluene, a better known reducing agent.

Animal Studies

Both the garlic oil and onion oil supplementation to nicotine-treated rats increased resistance to lipid peroxidation (Helen et al. 1999). The supplementation increased activities of antioxidant enzymes, catalase, superoxide dismutase and glutathione peroxidase and increased concentrations of glutathione. The results indicated that oils of garlic and onion were effective antioxidants against the oxidative stress.

Onion oil supplemented to nicotine-treated rats showed increased resistance to lipid peroxidation, and the effect was near to that of vitamin E-fed rats (Helen et al. 2000). On onion oil or vitamin E supplementation, the concentration of antioxidants was significantly raised in all the tissues studied; however, a significantly increased concentration of glutathione, vitamin E and retinol was noticed in vitamin E + nicotine-treated rats. Thus, the results indicated that onion oil was an effective antioxidant against the oxidative damage caused by nicotine as compared to vitamin E.

Studies showed that rats fed with diets of garlic or onions could reduce the exercise-induced oxidative stress but does not alter plasma cholesterol profile (Choi and Cho 2006). In garlic- or onion-fed animals, the ratio of reduced glutathione/oxidised glutathione was significantly higher than those of the control animals before and after exercise. The level of liver malondialdehyde (MDA) was lower than that of control animals after exercise. Compared to control animals, catalase activity of garlic-fed animals was higher before exercise but was lower after exercise, while superoxide dismutase (SOD) activity of garlic-fed animals was lower in before and after exercise. Catalase activity of onion-fed animals was higher before and during exercise, while SOD activity was higher during exercise. Plasma cholesterol profiles were not significantly different in rats fed with different *Allium* vegetable diets. The results suggested that *Allium* vegetable diets had antioxidative activities and could reduce the oxidative stress from exercise in rats but did not alter the plasma cholesterol profile.

Rats fed with onion flesh powder or onion peel powder had a higher plasma total antioxidant status than rats fed the onion-free control diet (Park et al. 2007). Onion peel powder reduced liver thiobarbituric reactive substances relative to those of the control diet in aged rats. Brain 8-isoprostane levels were markedly decreased by all four onion diets, and the decrease was significant for the onion flesh powder and onion peel powder diets. There was no significant decrease in cellular DNA damage in the kidney or brain tissue among rats fed with the four onion diets. Total antioxidant status (TAS) and levels of total polyphenols and quercetin were greatest in onion peel ethanol extract, followed by onion peel powder, onion flesh ethanol extract and onion flesh powder. Plasma quercetin and isorhamnetin levels were markedly increased by onion peel powder and onion peel ethanol extract. Onion flesh or onion peel enhanced antioxidant status in aged rats and may be beneficial for the elderly as a means of lowering the lipid peroxide levels. Feeding rats with dietary red onion peel and/or flesh was found to enhance antioxidant defence mechanism through the induction of plasma SOD and glutathione peroxidase (GPx) activities and inhibition of liver lipid peroxidation indicating that red onion may exert important protective effects against oxidative stress-related diseases (Lee et al. 2012a).

Clinical Studies

In a study on five healthy volunteers, following the onion meal, quercetin was found to be absorbed to high enough concentrations to increase the overall antioxidant activity of the plasma (McAnlis et al. 1999). Quercetin, however, had a strong affinity for protein and provided no direct protective effect during low-density lipoproteins (LDL) oxidation. In a separate human volunteer study, Moon et al. (2000b) found that after the short-term ingestion of onion rich in quercetin glucosides, conjugated metabolites of quercetin accumulated exclusively in human blood plasma in the concentration range of 10^{-7} to approximately 10^{-6} M, although these metabolites were hardly incorporated into plasma LDL. Human LDL isolated from the

plasma after the trial showed little improvement of its resistance to copper ion-induced oxidation. Overall, quercetin was the most effective inhibitor of oxidative damage to LDL in-vitro (O'Reilly et al. 2000). However, no significant difference was found in the Cu^{2+} ion-stimulated lag time of LDL oxidation in humans given a diet enriched with onions and black tea (high flavonoids) (48 minutes) and low-flavonoid dietary treatments (49 minutes). In a randomised crossover design of 32 healthy humans consumption of flavonoid-rich onion and black tea, predominantly the flavonoid quercetin, had no significant effect on plasma F2-isoprostane concentrations and MDA-LDL (malondialdehyde-modified low-density lipoprotein) autoantibody titre in the study and thus did not appear to inhibit lipid peroxidation in humans (O'Reilly et al. 2001).

Anticancer Activity

In-Vitro Studies

Organosulfur compounds (OSCs) in garlic and onion such as oil-soluble OSCs methyl propyl disulfide and propylene sulfide demonstrated inhibitory effects on the development of liver glutathione S-transferase placental (GST-P)-positive foci (Fukushima et al. 1997). Similarly water-soluble OSCs S-methylcysteine and cysteine decreased GST-P focus formation. In contrast, OSCs such as diallyl sulfide, diallyl trisulfide and allyl methyl trisulfide enhanced formation of such altered hepatocellular foci. Inhibitory potential for colon and renal carcinogenesis was observed in rats treated with diallyl disulfide. Thus, the results indicated that some OSCs exert chemopreventive effects on chemical carcinogenesis.

Incubation of human promyelocytic leukaemia cells HL-60 with garlic or onion oil (20 μg/mL) caused a marked suppression of HL-60 proliferation; the suppression was almost identical with those obtained by all-*trans*-retinoic acid (ATRA) or dimethyl sulfoxide (DMSO) used as positive controls (Seki et al. 2000). These oils induced the generation of nitroblue tetrazolium (NBT)-reducing activity, and about 20 % of the HL-60 cells became NBT positive. CD11b, another marker of the differentiation of these cells, was also significantly induced by garlic oil or onion oil. The data suggested that garlic and onion oils had the ability to induce differentiation of HL-60 cells into those of the granulocytic lineage. Quercetin inhibited the proliferation of HT-29 human colon cancer cells with an IC_{50} value of 81.2 μM (Wenzel et al. 2004). It was found that quercetin altered the levels of a variety of proteins involved in growth, differentiation and apoptosis of colon cancer cells.

The proliferation of HepG(2) and Caco-2 cells was significantly inhibited in a dose-dependent fashion after exposure to the Western Yellow, New York Bold and Northern Red onion and shallot extracts, with Western Yellow, shallots and New York Bold exhibiting the highest antiproliferative activity against HepG(2) cells and New York Bold and Western Yellow exhibiting the highest antiproliferative activity against Caco-2 cells (Yang et al. 2004). However, the varieties of Western White, Peruvian Sweet, Empire Sweet, Mexico, Texas 1015, Imperial Valley Sweet and Vidalia demonstrated weak antiproliferative activity against both HepG(2) and Caco-2 cells. Shallots contained the highest total phenolic content (114.7 mg/100 g of sample) among the varieties tested and exhibited the highest total antioxidant activity (45.5 μmol of vitamin C equiv./g of onion). For all varieties, both total phenolic and flavonoid contents were strongly correlated with total antioxidant activity ($R^2 = 0.9668$ and $R^2 = 0.7033$, respectively).

Quercetin aglycone was found to be the most effective inducer of the anticarcinogenic phase II marker enzyme, quinone reductase (QR), in mouse Hepalclc7 cells (Williamson et al. 1996). Of the onion purified glycosides (quercetin 3,4′-diglucoside and quercetin 4′-glucoside), only quercetin 4′-glucoside was able to induce QR activity in the assay. Inhibition of NADPH-/iron- and ascorbate-/iron-induced lipid peroxidation of human liver microsomes, and the Trolox C-equivalent antioxidant capacity (TEAC), assay showed that the 4′-glycosylation dramatically decreased activity in the 'antioxidant' assays, whereas 3-substitutions produced much smaller changes. The nonpolar

extracts of freeze-dried onion was found to contain potential cancer-preventive constituents based on the ability to induce quinone reductase (QR, a representative phase II enzyme) in murine hepatoma cells (Hepa 1c1c7) (Xiao and Parkin 2006). Five pure compounds were isolated from active fractions and identified as *p*-hydroxyphenethyl *trans*-ferulate; 5,6-dimethyl-2-pyridinecarboxylic acid; ferulic acid; 1-(6-hydroxy-[3]pyridyl)-propan-1-one and N-*trans*-feruloyl 3-*O*-methyldopamine. *p*-Hydroxyphenethyl *trans*-ferulate (1) doubled QR-specific activity in Hepa 1c1c7 cells at a level of 2.1 μg/mL (6.6 μM). One newly identified compound, 5-hydroxy-3-methyl-4-propylsulfanyl-5H-furan-2-one, and four known compounds, 5-(hydroxymethyl) furfural, acetovanillone, methyl 4-hydroxyl cinnamate and ferulic acid methyl ester, were also isolated from onion and identified as active quinone reductase inducing agents (Xiao and Parkin 2007). Results of in-vitro studies suggested that onion oil may exert chemopreventive action by inducing cell cycle arrest at the G2/M phase and apoptosis in A540 lung carcinoma cells (Wu et al. 2006). Hung (2007) found that quercetin-inhibited A549 lung carcinoma cell proliferation was associated with activation of the extracellular signal-regulated kinase (ERK). Inhibition of MEK1/2 but not PI3 kinase, p38 kinase or JNK abolished quercetin-induced apoptosis suggesting that MEK-ERK activation was required to trigger apoptosis. Treatment with different concentrations (0.5–1.5 mg/mL) of 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyranone (DDMP), isolated from onions, for various periods (0–48 hours) inhibited the growth of colon cancer cells (SW620 and HCT-116) followed by the induction of apoptosis in a dose-dependent manner (Ban et al. 2007) . It was also found that DDMP modulated tumour necrosis factor-alpha (TNF-alpha) and tetradecanoylphorbol acetate (TPA)-induced NF-kappaB transcriptional and DNA binding activity. In addition, DDMP suppressed the NF-kappaB target anti-apoptotic genes (Bcl-2), whereas it induced the expression of the apoptotic genes (Bax, cleaved caspase-3 and cleaved PARP).

Quercetin, flavonoid of onion, had been reported to inhibit the growth of certain malignant cells in-vitro and histamine and most cyclin-dependent kinases and also displayed unique anticancer properties (Shaik et al. 2006). It was found that MSTO-211H human malignant pleural mesothelioma cell viability was reduced, and apoptotic cell death was increased by quercetin (20–80 μM), with an IC_{50} value of 58 μM (Chae et al. 2012). In addition, quercetin increased the sub-G_1 cell population and was found to interact with specificity protein 1 (Sp1) and significantly suppressed its expression at the protein and mRNA levels. Furthermore, quercetin modulated the levels of Sp1 regulatory genes, such as cyclin D1, myeloid cell leukaemia (Mcl)-1 and survivin in MSTO-211H cells. Quercetin, a principal flavonoid compound in onion, inhibited migration and invasion of SAS human oral cancer cells (Lai et al. 2013). This was associated with the down-regulation of PKC and RhoA by suppressing MAPK and PI3K/AKT signalling pathways and NF-κB and uPA, resulting in inhibition of matrix metalloproteinase MMP-2 and MMP-9 expression and activation.

Fisetin, a flavonol found in onion, acted as a dual inhibitor of the PI3K/Akt and the mTOR pathways in prostate cancer and lung adenocarcinoma cells (Adhami et al. 2012; Syed et al. 2013) The Akt/mTOR pathway is known to play a central role in various cellular processes that contribute to the malignant phenotype. Dihydroquercetin (taxifolin), a potent flavonoid found in onions, had been reported to show therapeutic promise in major disease states such as cancer, cardiovascular disease and liver disease (Weidmann 2012). The proposed mechanism(s) of action reported included the activation of the antioxidant response element (ARE) and detoxifying phase II enzymes, inhibition of cytochrome P(450) and fatty acid synthase in carcinogenesis. Among the nine dihydroquercetin derivatives, the maximum antiproliferative activity on the model of rat fibroblast culture was exhibited by KN-2, KN-4, KN-7 and KN-8 compounds, while KN-7 and KN-8 compounds also showed maximum activity on the model of MCF-7 tumour (human breast cancer) cell culture (Rogovskiĭ et al. 2010). The maximum general antioxidant activity was observed for the native dihydroquercetin and

KN-8 compound. There was a strong correlation ($R^2 = 0.93$) between the antiproliferative effects of dihydroquercetin derivatives on murine skin fibroblasts and MCF-7 cells (human breast cancer). The dose of S-allylmercaptocysteine (CySSA) from garlic or S-1-propenylmercaptocysteine (CySSPe) (the major onion analogue) alone required to reduce viable breast cancer MCF-7 cells by 50 % was >400 μM, (Zhang et al. 2014). This was synergistically reduced to 62 and 91 μM for CySSA + Se and CySSPe + Se in the presence of Na_2SeO_3 (Se), respectively, at molar ratios of 39:1. Apoptosis was confirmed and cell cycle arrest occurred at the G2/M and sub-G1 interphases.

Onionin A isolated from onion bulb showed the potential to suppress tumour cell proliferation by inhibiting the polarisation of M2 alternatively activated macrophages (El-Aasr et al. 2010). Crude onion extract was cytotoxic to Lucena multidrug resistance (MDR) human erythroleukaemic and its K562 parental cell line (Votto et al. 2010). Similar sensitivities were obtained for both tumoral cells. In K562 cells, a significant increase of apoptosis was verified while the Lucena cells experienced a significant increase of necrosis. The onion extract also exhibited antioxidant effect and induced significant DNA damage in both tumoural cell lines. No significant cytotoxic effects were observed in either cell line treated with its components quercetin or propyl disulfide.

The fermented aqueous onion extract, lacking the usual onion flavonoid profile, was found to be the most active in antibacterial, antigenotoxic, and antiproliferative activity of these extracts was assessed by means of agar disc diffusion, bacterial growth kinetics, a comet assay, cell cycle distribution analysis and cell viability assays (Millet et al. 2012). The finding indicated that metabolites of onion compounds, generated by lactic acid fermentation, may be more active than their precursor substances.

Animal Studies

The tumour yield and incidence of phorbol-myristate-acetate promotion were inhibited in a dose-dependent manner over the range of 10–10,000 μg onion oil, applied three times per week (Belman 1983). Garlic oil was also inhibitory but was less effective. Eight organosulfur compounds from garlic and onions allyl methyl trisulfide (AMT), allyl methyl disulfide (AMD), diallyl trisulfide (DAT) and diallyl sulfide (DAS) and also four corresponding saturated compounds in which propyl groups were substituted for the allyl groups were tested for their inhibitory effects on benzo[a]pyrene (BP)-induced neoplasia of forestomach and lung of female A/J mice (Sparnins et al. 1988). DAS and AMD, but not DAT or AMT, inhibited pulmonary adenoma formation. All four allylic compounds induced increased glutathione S-transferase (GST) activity in the forestomach, but varied in their capacity to induce GST in lung, liver and small bowel. Their saturated analogues produced little or no induction. Studies on diethylnitrosamine-induced neoplasia of the liver in male F344 rats using the medium-term bioassay system based on the two-step model of hepatocarcinogenesis found that four organosulfur compounds from garlic and onions, isothiocyanic acid isobutyl ester, dipropyl trisulfide, allyl mercaptan and dimethyl trisulfide appeared to promote rat hepatocarcinogenesis (Takada et al. 1994a, b). Their promoting effect might be caused by increased cell proliferation with increased ornithine decarboxylase biosynthesis. Spermidine/spermine N1-acetyltransferase activity was not significantly changed.

Application of onion oil inhibited skin tumorigenesis in Sencar mouse initiated by 7,12-dimethylbenz[a]-anthracene (DMBA) and promoted in two tumour stages by 12-O-tetradecanoylphorbol-13-acetate (TPA) (Perchellet et al. 1990). The number of papillomas per mouse was significantly reduced by onion oil but not by propenyl sulfide. Onion oil inhibited the TPA-stimulated DNA synthesis when given as single doses of 5 mg one hour before TPA. Jung et al. (2008) reported that mouse skin tumorigenesis data clearly showed that pretreatment with myricetin significantly suppressed UVB-induced skin tumour incidence in a dose-dependent manner. Their results indicated that myricetin exerted potent chemopreventive activity mainly by inhibiting Fyn kinase activity directly and subsequently attenuated UVB-induced COX-2

expression in skin carcinogenesis. Also myricetin was found to inhibit UVB-induced angiogenesis by targeting PI3-K in an SKH-1 hairless mouse skin tumorigenesis model (Kang et al. 2011). Raf kinase was found to be a critical target for myricetin in inhibiting the UVB-induced formation of wrinkles and suppression of type I procollagen and collagen levels in mouse skin.

Administration of quercetin (active onion flavonoid) to BALB/c mice injected with leukaemia WEHI-3 cells inhibited proliferation of WEHI-3 and promoted an immune response (Yu et al. 2010). Quercetin decreased the percentage of Mac-3 and CD11b markers, suggesting that the differentiation of the precursors of macrophages and T cells was inhibited. There was no effect on CD3 levels, but quercetin increased CD19 levels. Quercetin decreased the weight of the spleen and liver compared with the olive oil-treated animals. Quercetin stimulated macrophage phagocytosis of cells isolated from peritoneum and also promoted natural killer cell activity.

Atypical prostatic hyperplasia-induced prostatic rats developed hyperplasia and inflammation with cellular proliferation and reduced apoptosis, accompanied by increased tissue expressions of proinflammatory cytokines IL-6, IL-8, TNF-α, IGF-1 and clusterin and decreased TGF-β1 which were all ameliorated by treatment with saw palmetto and red onion scale methanol extract (Elberry et al. 2014). These ameliorative effects were more evident in onion-treated groups and were dose dependent. Assay of total phenolic content of methanolic extract was determined to be 12.9 mg GAE/g DE. Quercetin and quercetin 4′-β-*O*-D-glucoside were identified as the major flavonoids, also sterols and/or terpenoids, and tannins were detected. The onion extract exhibited DPPH scavenging activity in a dose-related manner with IC_{50} value of 368 μg/mL. The protective effect against atypical prostatic hyperplasia I rats was ascribed to potential anti-inflammatory and immunomodulatory effects.

Epidemiological/Meta-analytical Studies

In the Zutphen Elderly Study of 738 men aged 65–84 years from 1985 to 1990, a high intake of flavonoids from vegetables and fruits (mainly onions, kale, endive and apples) was inversely associated with the risk of cancer of the alimentary and respiratory tract (relative risk of highest vs. lowest tertile = 0.51) (Hertog et al. (1994)). The Netherlands Cohort Study which started in 1986 with 120,852 men and women ranging in age from 55 to 69 years provided evidence for a strong inverse association between onion consumption and stomach carcinoma incidence (Dorant et al. 1996b). The rate ratio for stomach carcinoma in the highest onion consumption category (> or = 0.5 onions/day) was 0.50 compared with the lowest category (0 onions/day) after adjustment for other risk factors. The reduction in risk was restricted to carcinoma in the noncardia part of the stomach. The consumption of leeks and the use of garlic supplements were not associated with stomach carcinoma risk. The Netherlands Cohort Study did not support an inverse association between the consumption of onions and leeks or the use of garlic supplements and the incidence of male and female colon and rectum carcinoma (Dorant et al. 1996a). In a case-control study of 345 patients diagnosed with primary breast carcinoma between 1986 and 1989 conducted in France, Challier et al. (1998) found that accounting for total caloric intake and established risk factors, breast cancer risk was shown to decrease as consumption of fibre, garlic and onions increased. This study also supported the epidemiologic evidence that saturated fat intake and breast cancer risk are associated in postmenopausal women and conversely that unsaturated fat intake could lower the risk in the same subgroup. In an interview study of 582 patients with incident lung cancer and 582 age-, sex- and ethnicity-matched control subjects, Le Marchand et al. (2000) found that after adjusting for smoking and intakes of saturated fat and β-carotene, there was a statistically significant inverse associations between lung cancer risk and the main food sources of the flavonoids quercetin (onions and apples) and naringin (white grapefruit). The lung cancer odds ratio (OR) for the highest compared with the lowest quartile of intake was 0.5 for onions and 0.6 for apples. The OR for the highest compared with the lowest tertile of intake for white grapefruit was 0.5. No

association was found for important food sources of other flavonoids.

In a case-referent study conducted in Jiangsu province, China, on histopathologically confirmed cases for oesophageal cancer ($n=81$) and stomach cancer ($n=153$) and population-based referents ($n=234$), frequent intake of *Allium* vegetables (garlic, onion, Welsh onion and Chinese chives) was found to be inversely associated with the risk for both cancers (Gao et al. 1999). In the highest consumption category (> or = 1 time/week) of garlic, onion, Welsh onion and Chinese chives, the adjusted odd ratios compared with the lowest category (<1 time/month) were 0.30 (CI = 0.19–0.47), 0.25 (CI = 0.11–0.54), 0.15 (CI = 0.08–0.26) and 0.57 (CI = 0.23–1.42) for oesophageal cancer and 0.31 (CI = 0.22–0.44), 0.17 (CI = 0.08–0.36), 0.22 (CI = 0.15–0.31) and 0.40 (CI = 0.17–0.94) for stomach cancer, respectively. In an interview study, six of four patients with stomach cancer and 1,131 controls in an area of China with high rates of gastric cancer showed a significant reduction in gastric cancer risk with increasing consumption of garlic, onions and other *Allium* vegetables (You et al. 1989). Persons in the highest quartile of intake experienced only 40 % of the risk of those in the lowest. Protective effects were seen for *Allium* foods. In a large population-based case–control study in Shanghai (750 cases and 750 age- and gender-matched controls) and Qingdao (201 cases and 201 age- and gender-matched controls), Setiawan et al. (2005) found an inverse relationships with dose–response pattern that were observed between frequency of onion intake and stomach cancer in Qingdao and Shanghai after adjusting for matching variables, education, body mass index, pack-years of smoking, alcohol drinking, salt intake and fruit and vegetable intake. In Shanghai, negative dose–response relationships were observed between monthly intake of onions or garlic stalks and distal, but not cardia cancer. A negative association was also noted between intake of garlic stalks (often vs. never) and risk of stomach cancer in Qingdao (OR = 0.30). Our results confirmed protective effects of *Allium* vegetables (especially garlic and onions) against stomach cancer.

Using a large data set from an integrated network of Italian and Swiss case–control studies, Galeone et al. (2006) found an inverse association between the frequency of use of *Allium* vegetables and the risk of several common cancers. The multivariate odds ratios (ORs) for the highest category of onion and garlic intake were, respectively, 0.16 and 0.61 for cancer of the oral cavity and pharynx, 0.12 and 0.43 for oesophageal cancer, 0.44 and 0.74 for colorectal cancer, 0.17 and 0.56 for laryngeal cancer, 0.75 and 0.90 for breast cancer, 0.27 and 0.78 for ovarian cancer, 0.29 and 0.81 for prostate cancer and 0.62 and 0.69 for renal cell cancer. A large multi-centre case–control study of 1,369 patients with benign prostatic hyperplasia and 1,451 controls in Italy showed an inverse association between onion and garlic consumption and benign prostatic hyperplasia (Galeone et al. 2007); the inverse relationships were consistent across age strata. In a multicentre case–control study of 454 endometrial cancer cases and 908 controls, Galeone et al. (2009) found a moderate protective role of onion and garlic on the risk of endometrial cancer. Compared with nonusers, the odd ratio of endometrial cancer for successive categories of onion intake were 0.94 for < two portions/week and 0.40 for > or = two portions/week, with a significant inverse trend in risk. The odd ratio for an increment of one portion (i.e. 80 g) of onions per week was 0.81. For garlic, the odd ratio for successive categories of intake was 0.89 for intermediate use and 0.62 for high use, with a significant inverse trend in risk. In humans, the total average intake of quercetin and kaempferol was estimated at 20 mg/day, and the consumption of quercetin from onions and apples was inversely correlated with lung cancer risk (Hung 2007). In a meta-analysis, consumption of high levels of *Allium* vegetables (onion, garlic, leek, Chinese chive, scallion, garlic stalk and Welsh onion) reduced the risk for gastric cancer risk (Odds ratio, 0.54) (Zhou et al. 2011). Specific analyses for onion, garlic, leek, Chinese chive, scallion, garlic stalk and Welsh onion yielded similar results, except for onion leaf.

Antibacterial Activity

Fresh homogenised onion exhibited strong antimicrobial effect, 50–100 mg, completely inhibited the in-vitro growth of *Staphylococcus aureus* strain (Virtanen and Matikkala 1959a). It was found to contain S-methylcysteine sulfoxide (MCSO) and S-n-propyl cysteine sulfoxide (PCSO) or dihydroalliin, from which the corresponding thiosulfinates were formed enzymatically. These compounds also exhibited strong antimicrobial activity. All extracts of onion bulb were inhibitory in-vitro to *Escherichia coli*, *Pseudomonas pyocyaneus*, *Salmonella typhi* and *Bacillus subtilis* (Abdou et al. 1972). The ether extract gave the strongest inhibition followed by ethyl acetate, ethanol and petroleum ether extract.

All test organisms: five Gram-negative and three Gram-positive bacterial species and two yeast species were inhibited by garlic juice, while onion and shallot juice showed no effect upon Gram-negative bacteria (Dankert et al. 1979). Garlic extract showed greater activity against Gram-positive organisms, Gram-negative organisms as compared to the extract of onion (Elnima et al. 1983). Onion oil was highly active against all Gram-positive bacteria tested and only one isolate (*Klebsiella pneumoniae*) of Gram-negative bacteria (Zohri et al. 1995). Onion extract exhibited antibacterial activity in-vitro against *Streptococcus mutans* and *Streptococcus sobrinus*, the main causal bacteria for dental caries, and *Porphyromonas gingivalis* and *Prevotella intermedia*, the main causal bacteria of adult periodontitis (Kim 1997). Grated onion left to stand at 37 °C for 48 hour and steam treated (100 °C for 10 minutes) onion did not show antibacterial activity. The essential oil extracts of these *Allium* plants (garlic and green, yellow, red onions) exhibited marked antibacterial activity against *Staphylococcus aureus* and *Salmonella enteritidis*, with garlic showing the highest inhibition and green onion the lowest (Benkeblia 2004). Comparatively, 50 and 100 mL/L concentrations of onions extracts were less inhibitory than 200, 300 and 500 mL/L concentrations. However, with garlic extract, high inhibitory activity was observed for all tested concentrations. *S. aureus* showed less sensitivity towards essential oil inhibition; however, *S. enteritidis* was strongly inhibited by red onion and garlic extracts.

Quercetin derivatives from onion skin, 2-(3,4-dihydroxyphenyl)-4,6-dihydroxy-2-methoxybenzofuran-3-one, exerted selective activity against *Helicobacter pylori* strains and 3-(quercetin-8-yl)-2,3-epoxyflavanone showed antibacterial activity against methicillin-resistant *Staphylococcus aureus* (MRSA) and *H. pylori* strains at the same time that it increased susceptibility of MRSA to β-lactams (Ramos et al. 2006). Quercetin inhibited growth of periodontal pathogens *Actinobacillus actinomycetemcomitans* and *Porphyromonas gingivalis* in-vitro (Geoghegan et al. 2008, 2010). No significant difference was found between the chlorhexidine group and the quercetin solution after 24 hours of incubation.

Quercetin and kaempferol isolated from Spanish onions were inhibitory against Gram-positive bacteria such as *Bacillus cereus*, *Staphylococcus aureus*, *Micrococcus luteus* and *Listeria monocytogenes* (Santas et al. 2010). Gram-negative bacteria *Escherichia coli* and *Pseudomonas aeruginosa* were less sensitive, while *Candida albicans* was totally resistant. Among the onion extracts tested, only ethyl acetate subfraction showed antimicrobial inhibition. Thirty-three clinical isolates of *Vibrio cholera* were sensitive to onion extracts of two types (purple and yellow) (Hannan et al. 2010). Purple onion extract had MIC range of 19.2–21.6 mg/mL. The extract of yellow type onion had an MIC range of 66–68.4 mg/mL. The outer and inner layers of red onion showed antibacterial activity in-vitro against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* (two strains) (Benamalek et al. 2013). The largest inhibition zone was observed with flavonols of the inner layer of red onion (40 mm), inhibiting the Gram-negative *Escherichia coli*. Ethyl acetate fractions of onion showed inhibitory activities against all tested eight microbes including bacteria and a fungus, while chloroform fractions inhibited all the microbes except *Pseudomonas aeruginosa* (Bakht et al. 2014). Butanol fractions showed second highest activity at both lower and higher concentrations.

Ethanol and water fractions were found least effective or ineffective. Among Gram-positive microbes, *Staphylococcus aureus* was the most susceptible bacteria and the most resistant Gram-negative bacteria were *Pseudomonas aeruginosa* and *Salmonella typhi*.

Antifungal Activity

The fungus *Fusarium oxysporum* showed the lowest sensitivity towards the onion essential oil extract, whereas *Aspergillus niger* and *Penicillium cyclopium* were significantly inhibited particularly at low concentrations (Benkeblia 2004). Growth of two important dermatophytes, *Trichophyton rubrum* and *Trichophyton mentagrophytes*, was found to be strongly inhibited by aqueous onion extract as a dose-dependent manner (Ghahfarokhi et al. 2004). Onion extract showed fungicidal effect for both fungi at concentrations >3.12 % (v/v). The fungus *T. mentagrophytes* was more affected by the onion as compared to *T. rubrum* at all concentrations used. Onion oil (200 ppm) completely inhibited the growth of *Microsporum canis*, *M. gypseum* and *Trichophyton simii*, while the growth of both *Chrysosporium queenslandicum* and *Trichophyton mentagrophytes* was completely inhibited by 500 ppm of onion oil (Zohri et al. 1995). The growth of four other species of dermatophytic fungi was gradually reduced by increasing the concentrations of onion oil. Onion oil at different concentrations (100, 200 and 500 ppm) tested gradually reduced fungal growth and aflatoxin production by *Aspergillus flavus* and *A. parasiticus* var. *globosus*. Fungal growth and production of toxins sterigmatocystin and rubratoxin A by *A. versicolor* and *Penicillium rubrum* were completely inhibited by the addition of 200 ppm onion oil. Garlic and onion essential oils and their constituent diallyl trisulfide, diallyl tetrasulfide and dimethyl trisulfide were potent inhibitors of yeast growth with minimum inhibitory concentrations between 2 and 45 ppm (Kim et al. 2004a). Film formation on soy sauce by *Zygosaccharomyces rouxii* SS1 was completely prevented for 30 days by the addition of 30 and 40 ppm of garlic oil and onion oil, respectively. The oils and their constituent sulfides, however, were only very weakly antibacterial, showing minimum inhibitory concentrations of greater than 300 ppm for most of the bacteria tested.

Allium ampeloprasum and two *A. cepa* cultivars Junski srebrnjak and Kupusinski jabučar essential oils showed the strongest inhibitory effect against *Saccharomyces cerevisiae* at 1 % concentration (Kocić-Tanackov et al. 2009). Among onion cultivars, Kupusinski jabučar essential oil had stronger inhibition against *Candida tropicalis*, while *A. ampeloprasum* essential oil exerted no inhibition on this yeast. *Rhodotorula* sp. was inhibited only by *Allium ampeloprasum* essential oil. The strongest inhibitory effect on *Aspergillus tamarii* was shown by Kupusinski jabučar (57 % inhibition at 10 % concentration), and against *Penicillium griseofulvum*, the strongest inhibition was shown by *A. ampeloprasum* essential oil (78.3 % of inhibition at 10 % concentration). Junski srebrnjak and Kupusinski jabučar essential oils, at 7 and 10 % concentrations, respectively, completely inhibited the growth of *Eurotium amstelodami*.

Onion essential oil exhibited antimicrobial effect against food spoilage and food-borne pathogenic microorganisms with the MIC and MBC values in the ranges of 0.18–1.80 mg/mL and 0.54–3.6 mg/mL, respectively (Ye et al. 2013). Aqueous extracts prepared from onion garlic and the antifungal drug, ketoconazole, inhibited the growth of fungi *Malassezia furfur* (25 strains), *Candida albicans* (18 strains), other *Candida* sp. (12 strains) as well as 35 strains of various dermatophyte species tested in a dose-dependent manner with maximum of 100 % at defined concentrations (Shams-Ghahfarokhi et al. 2006). Compared to the garlic essential oil, the onion essential oil showed a stronger inhibitory effect on the *Aspergillus versicolor* mycelial growth and sterigmatocystin production (Kocić-Tanackov et al. 2012). After a 21-day incubation of the fungus 0.05 and 0.11 μg/mL of onion essential oil and 0.11 μg/mL of garlic essential oil completely inhibited *Aspergillus versicolor* mycelial growth and mycotoxin sterigmatocystin biosynthesis. The combination of essential oils of

onion (75 %) and garlic (25 %) had a synergistic effect on growth inhibition of *A. versicolor* and sterigmatocystin production.

Zwiebelane A (*cis*-2,3-dimethyl-5,6-dithiabicyclo [2.1.1]hexane 5-oxide), a natural product of onion bulbs, was found to enhance the potential fungicidal activity of polymyxin B (PMB) (Borjihan et al. 2010). Zwiebelane A amplified the disruptive effect of PMB on the vacuole of *Saccharomyces cerevisiae*.

Antiplatelet/Fibrinolytic Activity

After ingestion of fed-enriched breakfast without onions, fibrinolytic activity decreased in convalescent patients, but addition of dried (fried) or lyophilised (boiled) onions not only prevented the decrease but also caused a marked increase in fibrinolytic activity (Menon et al. 1968, 1969, 1970). Dried and lyophilised onions were found to increase blood fibrinolytic activity but had no effect on serum cholesterol levels, recalcified clotting times, thrombo tests and fibrinogen levels. Further, it was found that the property that caused an increase in fibrinolytic activity was inherent in fresh onions and not brought about by heating and that it was established to be heat stable and not water soluble. The least polar fraction of an oily chloroform extract of onion was found to contain most of the inhibitory activity towards platelet aggregation induced by either ADP or arachidonic acid (Makheja et al. 1979). The observed antiplatelet activity of onion was ascribed to the presence of a nonpolar, heat stable inhibitor of thromboxane synthesis. Nagda et al. (1983) found that only onion aqueous extract exhibited anticoagulant and fibrinolytic activity, while garlic extract and garlic oil were inactive. Alliin, (+)-*S*-allyl-L-cysteine sulfoxide, an active compound from *Allium cepa*, inhibited platelet aggregation in-vitro (Liakopoulou-Kyriakides et al. 1985). Onion oils exhibited antiasthmatic effect; it inhibited bronchial obstruction induced by platelet-activating factor (PAF) inhalation (Dorsch et al. 1987). Inhibition of platelet aggregation by onion was found to be mediated largely by a reduction on platelet thromboxane and lipoxygenase production from exogenous arachidonic acid (Srivastava 1986). *Allium cepa* var. *aggregatum* Don was shown to interfere with arachidonic acid metabolism of platelets (Gu et al. 1988). Cyclooxygenase products, thromboxane (TXA_2) and 12(S)-hydroxy-heptadecatrienoic acid (HHT) were decreased, while PGE_2 did not change. However, the product of lipoxygenase hydroxy-eicosatetraenoic acid (HETE) was increased. One of onion's thiosulfinates, diphenylthiosulfinate, inhibited PAF-induced bronchial hyperreactivity to histamine in guinea pigs (Dorsch et al. 1989). Quercetin the most prominent flavonoid in onions had shown great promise as an in-vivo antioxidant and platelet inhibitor but less promising results when studied in-vivo (Janssen et al. 1998). Results of in-vitro studies by Hubbard et al. (2003) showed that quercetin inhibited collagen-stimulated platelet aggregation via inhibition of multiple events in signalling generated by the collagen receptor GPVI.

Administration of aqueous extracts of garlic and onion, orally or intraperitoneally, daily for a period of 4 weeks exerted an antithrombotic on rats (Bordia et al. 1996). Thromboxane B2 (TXB2) level in the serum was inhibited, but boiled garlic and onion at high concentration (500 mg/kg) had very little effect on TXB2 synthesis. Infusion of a single dose 100 mg/kg onion extract did not elicit any inhibitory effect on TXB(2)synthesis in the serum of rabbit during the treatment period (Thomson et al. 2000). Goldman et al. (1996) found that onions with mild flavour and low sulfur content exhibited significantly lower antiplatelet activity than those containing high levels of sulfur. Antiplatelet activity was significantly positively correlated with genotypically determined bulb sulfur content and dissolved solids, indicating these latter factors to be good predictors of antiplatelet capacity. Onion showed dose-dependent inhibitory effects on the collagen-induced platelet aggregation, but this inhibition was of a lesser magnitude compared to garlic when related to dose (Ali et al. 1999). The concentration required for 50 % inhibition of the platelet aggregation for garlic was calculated to be approximately 6.6 mg/mL plasma, whereas the concentration for onion

was 90 mg/mL plasma. Boiled garlic and onion extracts showed a reduced inhibitory effect on platelet aggregation. Antiplatelet actions of aqueous extract of onion were investigated in rat and human platelet; IC_{50}values of onion extract for collagen-, thrombin- and arachidonic acid-induced aggregations and collagen-induced thromboxane A_2 formation were 0.17, 0.23, 0.34 and 0.12 g/mL, respectively (Moon et al. 2000a). In fura-2-loaded platelets, the elevation of intracellular Ca^{2+}concentration stimulated by collagen was inhibited by onion. They found that the mechanism for antiplatelet effect of onion may, at least partly, involve arachidonic release reduction, thromboxane A_2 synthase inhibition and thromboxane A_2/prostaglandin H_2 receptor blockade.

Studies by Briggs et al. (2001) suggested that the consumption of raw onion may help prevent platelet-mediated cardiovascular disorders. However, in-vitro incubations of onion juice demonstrated that the platelet inhibitory response was significantly greater in dog blood than in human blood. Onion showed a significant inhibitory effect on collagen- or arachidonic acid-induced thromboxane B(2) formation with greater potency in diabetic rat platelets than in normal rats (Jung et al. 2002). Similarly, more potent inhibitory effects of onion in diabetes were observed in collagen- or arachidonic acid-induced platelet aggregation and collagen-induced arachidonic acid release response. The results suggested that onion could produce more beneficial antithrombotic effect in diabetes.

A crude MeOH extract of brown onion scales (0.5–1.0 mg/mL) showed inhibitory effects on human platelet aggregation induced by collagen, adenosine 5′-diphosphate (ADP), thrombin and epinephrine (Furusawa et al. 2003). The antiplatelet extract (1.0 μg/mL) rigidified liposomal membranes by acting on the hydrocarbon core more intensively than the surface of membrane lipid bilayers. The flavonoidal components quercetin dimer 1, quercetin, quercetin dimer and quercetin 4′-glucoside (0.5–2 mM) inhibited collagen-induced platelet aggregation in increasing order of intensity. The antiplatelet flavonoids (0.25–10 μM) acted on liposomes of the lipid composition resembling human platelets to cause membrane rigidification which was greatest in the order of quercetin dimers (1 and 2), quercetin and quercetin 4′-glucoside. All freshly juiced onion extracts (ca. 5 minutes post-juicing) appeared to exhibit both an agonist-free aggregation peak (AFP) and a platelet inhibitory peak (PIP) characteristic of inhibition of platelet aggregation (Osmont et al. 2003). The AFP was minimal by 30 minutes and dissipated in all treatments by 120 minutes, while the PIP increased as onion extracts aged and did not change after 30 minutes at 25 °C. This finding confirmed the observation that the in-vitro platelet inhibitory activity of onion organosulfur compounds was time dependent. AFPs were abolished in apyrase-treated extracts, suggesting that this response may have been due to free ADP in onion extracts. Furthermore, platelet aggregates were not observed in the AFP, suggesting this response may be associated with changes in light transmission through platelet-rich plasma that were not associated with platelet aggregation. An onion variety, Toyohira, showed significant antithrombotic activity both in-vitro and in-vivo (Yamada et al. 2004). Toyohira showed thrombolytic activity in addition to the antiplatelet effect. Superkitamomiji, 2935A, and K83211 showed only thrombolytic activity.

In-vitro, multiwall carbon nano-onions (MWCNOs) exhibited the potent inhibitory effects on rat platelet aggregation caused by ADP in a concentration-dependent manner; platelet aggregation in the highest dosage of 20.0 μg/mL group was 50.0 % (Yang et al. 2011). In-vivo, the highest inhibitory was up to 20.4 %, but there was no significant difference, as compared with control group. The MWCNOs might inhibit platelet aggregation but did not affect hemostatic function. Multiwalled carbon nano-onions exerted inhibitory effect on platelet adhesion in-vitro, but in-vivo their injection via the caudal vein had no effects on the blood flow and wet weight of thrombus per millimetre in experimental thrombosis in rats (Yang et al. 2012b). Lee et al. (2013) found that oral supplementation of quercetin-rich onion peel extract (2 and 10 mg) influenced blood coagulation and arterial thrombosis in male Sprague-Dawley rats. The

results indicated that onion peel extract may have antithrombotic effects through restricting thrombin-induced expression of tissue factor in human umbilical vein endothelial cells (HUVECs) via downregulating mitogen-activated protein kinase (MAPK) activation upon coagulation stimulus, leading to the prolongation of time for arterial thrombosis. Collagen-induced in-vitro platelet aggregation was significantly reduced by tearless onion extract (with repressed lachrymatory factor synthase activity) over normal onion extract (Thomson et al. 2013).

An onion extract possessed anticoagulative activity apparently by inhibiting thrombin, and it was dependent upon the concentration of onion extract added (Kim et al. 2002). Boiling the onion extract at 100 °C for 30 minutes did not alter its anticoagulative activity compared to that of fresh onion. The anticoagulative activity of the onion extract was also retained after an acid treatment by incubating at pH 2.0 for 4 hours. However, dialysis of the extract substantially eliminated the anticoagulative activity. Hansen et al. (2012) found that steam cooking rapidly destroyed onion-induced antiplatelet activity. Extracts from cooked onion had the potential to reverse the inhibitory effect on blood platelets by 25 % without affecting the polyphenolic concentration. Although heating was, in general, detrimental for onion in-vitro antiplatelet activity (IVAA), the extent of this effect varied greatly, from unaffected antiplatelet activity (AA) (i.e. similar to raw onion) to a complete loss of activity, depending upon the manner in which onions were prepared prior to heating, the cooking method used and the intensity of the heat treatment (Cavagnaro and Galmarini 2012). 'Whole', 'quarters' and 'crushed' onions lost their IVAA after 30, 20 and 10 minutes of oven heating, respectively. The longer retainment of AA in intact bulbs was attributed to a later alliinase inactivation. Proaggregatory effects observed in samples subjected to the most intense oven and microwave heat treatments suggested that extensively cooked onions may stimulate rather than inhibit platelet aggregation.

Platelet aggregation in human subjects was inhibited 30 and 120 minutes after ingestion of 150 mg and 300 mg doses of quercetin 4′-*O*-β-D-glucoside (Hubbard et al. 2004). Correspondingly, collagen-stimulated tyrosine phosphorylation of total platelet proteins was inhibited. This was accompanied by reduced tyrosine phosphorylation of the tyrosine kinase Syk and phospholipase Cgamma2, components of the platelet glycoprotein VI collagen receptor signalling pathway. In a double-blind randomised crossover pilot study, ingestion of onion soup high in quercetin by subjects inhibited collagen-stimulated platelet aggregation and collagen-signalling pathway via glycoprotein VI, Syk (Hubbard et al. 2006). The inhibition of Syk tyrosine phosphorylation was correlated with the area under the curve for the high-quercetin plasma profile. The study further substantiated the epidemiological data suggesting that those who preferentially consume high amounts of quercetin-containing foods have a reduced risk of thrombosis and potential CVD risk.

Cardiovascular Protective/ Antiatherosclerotic Activity

Oral administration of petroleum ether extract of *Allium cepa* in albino rats significantly prevented the rise in serum cholesterol and serum triglyceride level, caused by atherogenic diet (Lata et al. 1991). It also conferred significant protection against atherogenic diet-induced atherosclerosis. *Allium* intake has been associated with significant reductions in blood pressure, cholesterol and platelet aggregation (Block 1992). When eaten raw on a regular basis, onion will promote the general health of the body. When used regularly in the diet, onion counteracts tendencies towards angina, arteriosclerosis and heart attack. Studies found that the preventative effect of quercetin on angiotensin II-induced smooth muscle cell (VSMC) hypertrophy was attributable, in part, to its inhibitory effect on Src homology and collagen (Shc)-activation and PI3-K-dependent c-Jun N-terminal kinase (JNK) activation in VSMC (Yoshizumi et al. 2001). Thus, inhibition of JNK by quercetin may imply its usefulness for the treatment of cardiovascular diseases relevant to VSMC growth.

On incorporation of 5 % garlic, amla or onion separately in the animal fat (butter fat, beef) diets to albino rats for 3 months, each of them ameliorated the deleterious effects of the animal fats (Augusti et al. 2001). Butter fat was found to be more atherogenic than beef. The order of ameliorative effects of the vegetables were garlic > amla > onion. The better hypolipidaemic effects and correction of elevated levels of certain enzymes shown by garlic and amla may be due to the facts that they contain comparatively better active principles than that found in onions.

Terao et al. (2008) found that quercetin metabolites glucuronides and/or sulfate conjugates circulating in the human blood stream were mostly localised in plasma albumin fraction, but not LDL fraction. Onion consumption failed to enhance the antioxidant activity of plasma fraction against LDL oxidation, indicating that the level of quercetin metabolites bound to albumin was insufficient to exert the antioxidative effect in-vivo. In contrast, they discovered that quercetin metabolites accumulated in the aorta tissue and exerted their antioxidant activity, when rabbits were fed with quercetin glucoside and high-cholesterol diet. Further, quercetin metabolites were detected in human atherosclerotic aorta exclusively. These implied that quercetin metabolites were incorporated into the atherosclerotic region and acted as complementary antioxidants, when oxidative stress was loaded in the vascular system.

The methanolic extract of onion attenuated ischaemia-/hypoxia-induced apoptotic death in murine heart H9c2 cells in-vitro and in rat heart in-vivo through, at least in part, an antioxidant effect (Park et al. 2009) The onion extract (0.05 g/mL) inhibited the elevation of the ROS, mitochondrial membrane depolarisation, cytochrome c release and caspase-3 activation during hypoxia in H9c2cells. In the in-vivo rat myocardial infarction model, onion extract (10 g/kg) significantly reduced the infarct size, the apoptotic cell death of the heart and the plasma MDA (malondialdehyde) level. Administration of onion extract to atherosclerotic rats decreased atherosclerotic lesions and increased endogenous aortic H_2S production, but decreased plasma ADM content, aortic ADM content and aortic CRLR, RAMP2 and RAMP3 mRNAs (Li et al. 2011). In addition, it increased plasma GSH-PX level and SOD activities but reduced MDA; it decreased inflammatory response but increased plasma eNOS activity and NO content.

Oral administration of onion extract restored the liver and kidney toxicities and blood dysproteinaemia and lipid dyslipidaemia (increased total cholesterol, triglycerides, LDL cholesterol and serum albumin and reduced HDL cholesterol, total plasma protein and plasma testosterone) induced by cadmium in rats (Ige and Akhighe 2013). Further, the onion extract improved Cd-induced decrease in urinary volume and renal clearance and also protected against Cd-induced oxidative stress by normalising redox status. The results provided the evidence of the therapeutic efficacy of onion extract against atherosclerotic conditions and organ toxicity in Cd-intoxicated rats. Administration of onion extract in rats exhibited antiapoptotic potential on doxorubicin (DOX)-induced apoptosis in aortic endothelial cells (Alpsoy et al. 2013b). DOX-treated with onion extract groups also showed a significant decrease in malondialdehyde levels and increased levels of glutathione in comparison with the DOX-treated group. Data showed that prevention of endothelial cell apoptosis by onion extract may contribute to the restoration of aortic endothelial dysfunction induced by DOX. Further, they found that the DOX-treated with onion extract rats showed a significant decrease in malondialdehyde levels and increased activities of superoxide dismutase, glutathione and glutathione peroxidase in comparison with the DOX-treated group (Alpsoy et al. 2013a). Creatine kinase, creatine kinase MB, lactate dehydrogenase activities and cardiac troponin I levels were significantly decreased in the DOX + onion group in comparison with the DOX group. These biochemical and histological disturbances were effectively attenuated on pretreatment with onion extract. Intragastric intubation of onion extract to cadmium-induced cardiotoxic rats for 30 days attenuated the adverse toxic effects of cadmium possibly through its antioxidant and antiapoptotic activity (Alpsoy et al. 2014). Onion extracted reverted the increased tissue malondialdehyde

(MDA) levels and decreased levels of the enzymatic antioxidants superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and catalase (CAT) caused by cadmium intoxication in cardiac tissue. Histological abnormalities caused by cadmium such as myofibrillar loss, vacuolisation of cytoplasm and irregularity of myofibrils were effectively attenuated by the treatment by onion extract. Also, onion extract significantly reduced apoptosis in the cardiomyocytes of the cadmium group.

Studies suggested that chronic onion extract intake for 30 days ameliorated postprandial endothelial dysfunction by an oral maltose load in healthy men and may be beneficial for improving cardiovascular health (Nakayama et al. 2013).

Hypotensive Activity

Dietary onion decreased the thiobarbituric acid-reactive substances (TBARS) in plasma in L-NAME-induced-hypertensive rats and stroke-prone spontaneously hypertensive rats (SHRSP) (Sakai et al. 2003). Also, onion increased the nitrate/nitrite (products of nitric oxide (NO)) excreted in urine and the NO synthase (NOS) activity in the kidneys in SHRSP. The results suggested that the increased NO caused by the greater NOS activity, and additionally by the increased saving of NO by the antioxidative activity of onion, was one of the causes of the antihypertensive effects of onion in SHRSP. In the L-NAME-induced-hypertensive rats, onion did not significantly block the inhibition of NOS activity by L-NAME, and decreased nitrate/nitrite excretion in urine was not restored. Raw onion significantly reduced the increase in systolic blood pressure in both L-NAME-induced-hypertensive rats and spontaneously hypertensive rats (SHR) and inhibited the increase in thiobarbituric acid-reactive substances (TBARS) and conjugated dienes in the plasma and tissues of SHR (Kawamoto et al. 2004). Boiling negated the antihypertensive effect as a result of a decrease in antioxidative activity. Quercetin-supplemented diets lowered blood pressure, attenuated cardiac hypertrophy in rats with aortic constriction and normalised cardiac protein kinase C betaII translocation (Jalili et al. 2006). The results supported an antihypertensive and antihypertrophic effect of quercetin in-vivo in the absence of changes concerning vascular and myocardial function. Intravenous administration of garlic, onion, ginkgo extracts produced dose-dependent and reversible hypotensive and bradycardic effects in anesthetised normotensive rats (Brankovic et al. 2011). The most effective in reducing arterial blood pressure and heart rate was garlic extract.

Studies by Naseri et al. (2008) showed that onion peel hydroalcoholic extract dose dependently reduced murine aorta contractions induced by KCl or phenylephrine possibly via inhibition of calcium influx but without involving NO, cGMP, endothelium and prostaglandins. The onion peel hypotensive effect could be due to extract quercetin content, antioxidant activity and inhibiting vascular smooth muscle cells Ca2+ influx.

In an open and a randomised, placebo-controlled, double-blind, crossover phase-I study, a spontaneous pharmacological effect 5 hours after administration of an onion–olive oil maceration capsule formulation on arterial blood pressure could be demonstrated in apparently healthy subjects (Kalus et al. 2000). In addition to a decrease in arterial blood pressure, a significant reduction in plasma viscosity and haematocrit was observed. In a subsequent study of 24 patients with arterial hypertension (WHO class I), administration of onion–olive oil maceration product (capsule) after a week led to a significant decrease in systolic blood pressure (Mayer et al. 2001) There was also a trend towards a decrease in diastolic blood pressure. The improved blood fluidity observed resulted from a decrease in haematocrit. In a separate randomised, double-blind, placebo-controlled, crossover study of men and women with prehypertension ($n=19$) and stage 1 hypertension ($n=22$), quercetin supplementation was found to reduce blood pressure in hypertensive subjects, but did not later reduce blood pressure in prehypertensive patients (Edwards et al. 2007). After

quercetin supplementation, reductions in systolic (−7 mmHg), diastolic (−5 mmHg) and mean arterial pressures (−5 mmHg) were observed in stage 1 hypertensive patients. Contrary to animal-based studies, there was no quercetin-evoked reduction in systemic markers of oxidative stress.

Antiobesity/Antihypercholesterolemic Activity

Administration of onion extract to sucrose-fed rabbits significantly reduced serum, liver and aorta triglycerides and serum and liver proteins (Sebastian et al. 1979). In contrast, liver-free amino acids were significantly increased in the onion-treated group as compared to the sucrose-fed control. The effects of onion were ascribed to its sulfur-containing principles which oxidised thiol compounds either present free or combined in a protein and NADPH which were necessary for lipid synthesis. Streptozotocin-induced diabetic rats fed with onion diet exhibited lowered lipid peroxides in circulation and in urine when compared to diabetic control group (Babu and Srinivasan 1997). Plasma cholesterol from LDL-VLDL fraction phospholipids and triglycerides was lowered significantly by dietary onion in diabetic animals. Hepatic cholesterol, triglycerides and phospholipids which were elevated under diabetic condition were lowered significantly by dietary onion. Thus, the study revealed that onion feeding improved the metabolic status in diabetic condition, probably because of its hypoglycaemic as well as hypocholesterolaemic effect.

In HepG2 cells, S-propyl cysteine decreased the secretion of apolipoprotein B100 (Han et al. 2002). The compound reduced the secretion of newly synthesised triacylglycerol and cholesterols from radiolabeled acetate. Administration of onion *S*-methyl cysteine sulfoxide (SMCS) and two standard drugs, glibenclamide and insulin, to alloxan-induced diabetic rats for 2 months ameliorated the diabetic condition significantly, viz., maintenance of body weight and control of blood sugar in rats (Kumari and Augusti 2002). Further, they lowered the levels of malondialdehyde, hydroperoxide and conjugated dienes in tissues exhibiting antioxidant effect on lipid peroxidation in experimental diabetes. This was achieved by their stimulating effects on glucose utilisation and the antioxidant enzymes, viz., superoxide dismutase and catalase. In a subsequent study, administration of onion *S*-methyl cysteine sulfoxide (SMCS) at a dose of 200 mg/kg body weight for 45 days ameliorated the hyperlipidaemic condition in high-cholesterol diet-fed rats (Kumari and Augusti 2007). The lipid profile in serum and tissues showed that concentrations of cholesterol, triglyceride and phospholipids were significantly reduced when compared to their untreated counterparts. The total lipoprotein lipase activity in the adipose tissue was decreased with also a decrease in the free fatty acid levels in serum and tissues. The activities of the lipogenic enzymes glucose 6-phosphate dehydrogenase and malic enzyme as also of HMG CoA reductase in the tissues remained low on treatment indicating that both the drugs did not favour lipogenesis and cholesterogenesis in the hyperlipidaemic animals. The faecal excretion of bile acids and sterols was further increased upon treatment with onion SMCS.

Supplementation of cycloalliin, a sulfur-containing imino acid in onions, at 0.1 % and 0.3 % levels to the atherogenic diet of Sprague-Dawley rats, reduced serum triacylglycerol (TAG) concentration by approximately 40 % compared to the control and also serum cholesterol ester level (Yanagita et al. 2003). Dietary cycloalliin had no significant effect on hepatic enzyme activities responsible for TAG synthesis. The study showed that dietary cycloalliin had serum TG-lowering effect without affecting hepatic TAG synthesis and content in rats, suggesting an alteration of lipoprotein assembly and secretion processes in the liver. Feeding hamsters for 8 weeks with onion powder dose dependently decreased plasma total cholesterol (TC) level (Guan et al. 2010). The change in plasma lipoprotein profile was accompanied by a greater excretion of both faecal neutral and acidic sterols. It was found that the hypocholesterolaemic activity of onion powder was mediated by enhancement of faecal sterol excretion and upregulation of liver X receptor alpha (LXRα)

and cholesterol-7α-hydroxylase (CYP7A1). Both raw red onion and white onion subjected to blanching for 90 seconds hindered elevation in plasma lipids more than the other vegetables studied in the supplemented diets (Gorinstein et al. 2010). Blanching for 90 seconds most fully preserved the bioactive compounds and antioxidant potentials and hindered the rise in plasma lipid levels and the decrease in plasma antioxidant activity of rats fed with cholesterol.

Ethyl acetate extract of onion (EEO) had potent inhibitory effects on animal fatty acid synthase (FAS) and could induce apoptosis in FAS overexpressing human breast cancer MDA-MB-231 cells (Wang et al. 2012). It was also found that EEO could suppress lipid accumulation during the differentiation of 3T3-L1 adipocytes, which was also related to its inhibition of intracellular FAS activity. Since obesity is closely related to breast cancer and obese patients are at elevated risk of developing various cancers, these findings suggested that onion might be useful for preventing obesity-related malignancy.

Quercetin-rich onion peel extract supplementation to diet-induced obese rats for 8 weeks reduced mesenteric fat weights and increased adiponectin mRNA expressions (Kim et al. 2012). Interleukin 6 mRNA levels (perirenal and mesenteric fats) in the onion-treated group were slightly lower than those in the high-fat group. Quercetin-rich onion peel extract (OPE) markedly suppressed lipid accumulations and triglyceride contents in 3T3-L1 preadipocytes and inhibiting adipogenesis in high-fat-fed rats (Moon et al. 2013). Body weight, retroperitoneal and mesenteric fat weights of rats were significantly lower in the 8-week high-fat (HF) diet + 0.72 % OPE group than in the HF group. The mRNA levels of activating protein (AP2) were downregulated, and those of carnitine palmitoyltransferase-1 α (CPT-1α) and fatty acid binding protein 4 (FABP4) were upregulated by 75 and 100 μg/mL OPE. Peroxisome proliferator-activated receptor (PPAR) γ mRNA and CCAAT/enhancer binding protein (C/EBP)α mRNA levels were downregulated in the epididymal fat of OPE than those of control and HF groups. The mRNA levels of CPT-1α and uncoupling protein-1 (UCP-1) were upregulated by the OPE, while those of fatty acid synthase (FAS) and acetyl-CoA carboxylase (ACC) were downregulated in HF and OPE groups compared to control group. A preliminary rat feeding trial indicated that the tearless onions (with repressed lachrymatory factor synthase activity) may also play a key role in reducing weight gain (Thomson et al. 2013).

In a randomised controlled clinical trial, raw red onion consumption appeared to be effective as a cholesterol-lowering food agent in obese and overweight women with polycystic ovary syndrome (Ebrahimi-Mamaghani et al. 2014). Onion significantly decreased the levels of total cholesterol and low-density lipoprotein cholesterol within each group; however, these changes were stronger in the high-onion group than in the low-onion group. The levels of fasting blood sugar, triglycerides, high-density lipoprotein cholesterol and lipoprotein (a) did not differ significantly after 8-week onion treatment.

Antihyperglycaemic/Antidiabetic Activity

Oral administration of the hypoglycaemic fraction of onion juice to alloxan-diabetic rabbits improved their glucose tolerance; the juice was about half as active as phenformin in lowering the fasting blood sugar (Mathew and Augusti 1975). Juice-expressed residue of onion, when fed to diabetic patients along with their food, controlled the hyperglycaemia effectively. Kumari et al. (1995) found that oral administration of S-methyl cysteine sulfoxide (SMCS), a sulfur-containing amino acid isolated from onion daily at a dose of 200 mg/kg body weight for a period of 45 days to alloxan-diabetic rats controlled significantly their blood glucose and lipids in serum and tissues and altered the activities of liver hexokinase, glucose 6-phosphatase and HMG CoA reductase towards normal. The above effects of SMCS were comparable to those of glibenclamide and insulin. Sheela et al. (1995) showed that oral administration of onion and garlic sulfoxide amino acids, viz., S-methylcysteine

sulfoxide (SMCS) and S-allylcysteine sulfoxide (SACS) to alloxan-diabetic rats for a month, ameliorated their diabetic condition, being characterised by glucose intolerance, weight loss, depletion of liver glycogen, etc., was ameliorated as comparable to rats treated with glibenclamide and insulin. Administration of onion solution increased the fasting serum high-density lipoprotein levels and demonstrated alleviation of hyperglycaemia in streptozotocin-diabetic rats (Campos et al. 2003). The hypoglycaemic and hypolipidaemic actions of *A. cepa* were associated with antioxidant activity, since onion decreased superoxide dismutase activities, while no increased lipid hydroperoxide and lipoperoxide concentrations were observed in diabetic rats treated with onion.

Oral administration of garlic or onion juice daily for 4 weeks to alloxan-induced diabetic rats reverted the adverse biochemical changes induced by alloxan such as significant elevation of plasma levels of glucose, urea, creatinine and bilirubin; significant increase of aspartate aminotransferase (AST), alanine aminotransferase (ALT), lactate dehydrogenase (LDH) and alkaline and acid phosphatases (AlP, ACP) activities in plasma and testes and their reduction in the liver; significant increase in brain LDH; increase in concentration of thiobarbituric acid-reactive substances and the activity of glutathione S-transferase in the plasma, liver, testes, brain and kidney (El-Demerdash et al. 2005). Compared to consumption of fenugreek and onion, only consumption of garlic by alloxan-induced diabetic rats was able to reduce blood glucose significantly compared with the control group (Jelodar et al. 2005). In the control positive group, all the mentioned morphometric factors volume density of B cells, volume density of islets, per cent of B cells, number of islets per square millimetre, average area of islets and average volume density of B cell in whole pancreas were significantly changed in comparison with the control negative (normal health) group, but the same did not show significant change between treated and untreated diabetics.

Islam et al. (2008) found that high-fat onion diet may increase insulin secretion and consequently insulin resistance in a dose-dependent manner, resulting in a worsened hyperglycaemic and hyperlipidaemic streptozotocin-diabetic rat and that higher dietary fat may impair the antidiabetic effects of dietary onion intake. Supplementation of onion powder decreased blood glucose, total serum lipid, triglyceride and atherogenic index and increased HDL cholesterol/total cholesterol ratio in streptozotocin-induced diabetic rats (Bang et al. 2009). Also, onion reduced renal oxidative stress in streptozotocin-induced diabetic rats.

Ethyl alcohol extract of onion skin had the highest α-glucosidase inhibitory activity, ORAC (oxygen radical absorbance capacity) antioxidant value and total phenolic content, followed by water extract of skin, ethyl alcohol extract of pulp and water extract of pulp (Kim et al. 2010). Ethyl alcohol extract of onion skin had highest quercetin content 209.22 mg/100 g FW followed by water extract of onion skin 15.94 mg, water extract of onion pulp 0.64 mg and ethyl alcohol extract of onion pulp 0.33 mg. Quercetin, a major phenolic compound in onion extract, had high α-glucosidase inhibitory activity. The α-glucosidase inhibitory activity of the onion extracts correlated to the phenolic content and antioxidant activity of the extracts. The results suggested that onion with high-quercetin content had the potential to contribute as a dietary supplement for controlling hyperglycaemia and oxidative stress-linked diabetes complications. Onion peel extract (OPE) containing high-quercetin ameliorated hyperglycaemia and insulin resistance in high-fat diet/streptozotocin-induced diabetic rats (Jung et al. 2011). The data suggested that OPE might improve glucose response and insulin resistance associated with type 2 diabetes by alleviating metabolic dysregulation of free fatty acids, suppressing oxidative stress, upregulating glucose uptake at peripheral tissues and/or downregulating inflammatory gene expression in the liver. Moreover, in most cases, OPE showed greater potency than pure quercetin equivalent. Body and adipose tissue weights in 5 % of onion extract-fed diabetes-prone Zucker diabetic fatty rats were found to be significantly lower than the control group without onion extract (Yoshinari et al

2012). Fasting blood glucose and HOMA-IR (homeostasis model of insulin resistance) levels were also improved, although the serum insulin and leptin levels did not show any remarkable difference. Serum triglyceride and free fatty acid levels in both the 3 % and 5 % onion-fed group were found to be reduced compared to the control group. Additionally the feeding of the onion extract increased the glucose tolerance. Cycloalliin, S-methyl-L-cysteine, S-propyl-L-cysteine sulfoxide and dimethyl trisulfide especially S-methyl-L-cysteine sulfoxide were reported to be effective in inhibiting formation of oil drop in the cells, suggesting that these compounds may be involved in the antiobesity effect of the onion extract.

Ethyl alcohol extract of onion skin (EOS) and its major flavonoid quercetin inhibited in-vitro rat intestinal sucrose with IC_{50} values of 0.40 and 0.11 mg/mL, respectively (Kim et al. 2011). The content of quercetin in ethyl alcohol extract of onion skin (EOS) was 6.04 g/100 g dried weight of onion skin. In rats fed on sucrose, EOS significantly reduced the blood glucose spike after sucrose loading. The results indicated that although quercetin does have blood glucose-lowering potential via α-glucosidase inhibition, other bioactive compounds were also present in onion skin. In-vivo, in Sprague-Dawley (SD) rat model, the activities of sucrase in the lower parts of intestine remained significantly higher after 2 weeks of EOS treatment. The results indicated that EOS may improve exaggerated postprandial spikes in blood glucose and glucose homeostasis since it inhibited intestinal sucrase and thus delayed carbohydrate absorption. Onion peel extract supplementation to rats fed a high-fat diet reverted high-fat-induced reduction in mRNA levels of sterol regulatory element-binding protein-2, low-density lipoprotein receptor and hydroxyl-3-methylglutaryl coenzyme reductase genes in the liver comparable with the levels of the control group (Lee et al. 2012b). Onion peel extract slightly increased stearoyl-coA desaturase 1 (SCD-1) expression and enhanced expression of ATP-binding cassette transporter A1, peroxisome proliferator-activated receptor γ2 and scavenger receptor class B type I genes compared with high-fat feeding. Their results suggested that onion peel altered the expression of genes associated with cholesterol metabolism in favour of lowering blood low-density lipoprotein cholesterol and enhancing high-density lipoprotein cholesterol through increasing mRNA abundance of low-density lipoprotein receptor and ATP-binding cassette transporter A1 genes.

Ingestion of crude onion (100 g) caused a considerable reduction in fasting blood glucose levels by about 89 mg/dL in relation to insulin (145 mg/dL) in type 1 diabetic patients, and it reduced fasting blood glucose levels by 40 mg/dL, compared to glibenclamide (81 mg/dL) in type 2 diabetic patients, 4 hours later (Taj Eldin et al. 2010). The same dose of crude onion produced a significant reduction in the induced hyperglycaemia (glucose tolerance test (GTT)) by about 120 mg/dL compared to water (77 mg/dL) and insulin (153 mg/dL) in type 1 diabetic patients and considerably reduced GTT by 159 mg/dL in relation to water (55 mg/dL) and glibenclamide (114 mg/dL) in type 2 diabetic patients, after 4 hours. The results suggested that crude onion could be used as a dietary supplement in management of type 1 and/or type 2 diabetes mellitus.

The results of the meta-analysis conducted by Kook et al. (2009) suggested that onion extract intake and single component (including S-allylcysteine sulfoxide, S-methylcysteine sulfoxide and diallyl trisulfide) intake may be effective for lowering plasma glucose concentrations and body weight. In the meta-analysis, the antidiabetic effects of onion extract and single components were significant for glucose concentration and body weight, but the effects of garlic extract were not significant.

Alliuocide G and four other known flavonoids isolated from the dried outer onion scales exhibited potent α-amylase inhibitory activity (Mohamad 2008). Alliuocide G also exhibited antioxidant activity. Quercetin was identified as a major flavonoid α-glucosidase inhibitor in *Allium* species including *A. cepa* (Schmidt et al. 2014). *N-p*-coumaroyloctopamine and *N-p*-coumaroyltyramine were also identified as major α-glucosidase inhibitors.

Anti-inflammatory/Antiasthmatic Activity

Oral pretreatment of guinea pigs with onion extract markedly reduced the asthmatic response induced by ovalbumin (Dorsch and Weber 1984). After onion pretreatment, near normal values were obtained after 30 seconds challenge (0.04 mL compared to 0.24 mL in the control) and only slightly increased values after 60 seconds challenge (0.16 mL compared to 0.33 mL in the control). Five alk(en)ylsulfinothioic acid alk(en)yl-esters isolated from onions and four synthetic thiosulfinates inhibited 5-lipoxygenase of porcine leucocytes, histamine release and leukotriene B_4 and C_4 biosynthesis of human polymorphonuclear leucocytes, thromboxane B_2 biosynthesis by human platelets and allergen-induced and PAF-induced bronchial obstruction of guinea pigs (Dorsch et al. 1988). The results suggested that the antiasthmatic and anti-inflammatory effects of onions depended in part on the thiosulfinate moiety. Nine thiosulfinates (TS) and four 'cepaenes' isolated from onions and/or synthetised showed dose-dependent (0.25–100 μM) marked inhibitory effects on both cyclooxygenase from sheep seminal vesicle microsomes and 5-lipoxygenase activity from porcine leucocytes (Wagner et al. 1990). The following rank order of activity was observed: saturated aliphatic TS < aromatic TS ≈ α,β-unsaturated TS < cepaenes. Cepaenes inhibited both cyclooxygenase and 5-lipoxygenase by more than 75 % at 10 and 1 μM concentrations, respectively.

Seven different synthetic thiosulfinates and cepaene- and/or thiosulfinate-rich onion extracts were found to inhibit in-vitro the chemotaxis of human granulocytes induced by formyl-methionine-leucine-phenylalanine in a dose-dependent manner and at a concentration range of 0.1–100 μM (Dorsch et al. 1990). Diphenylthiosulfinate showed the highest activity and was found to be more active than prednisolone. The results indicated that anti-inflammatory properties of onion extracts were related, at least in part, to the inhibition of inflammatory cell influx by thiosulfinates and cepaenes. Quercetin had been reported to block substances involved in allergies and to be able to act as an inhibitor of mast cell secretion, causing a decrease in the release of tryptase, MCP-1 and IL-6 and the downregulation of histidine decarboxylase (HDC) mRNA from few mast cell lines (Shaik et al. 2006). In a 3-way, single-blind, randomised cross-over study of eight subjects, quercetin conjugates were detected in plasma (up to a maximum concentration of 4 μmol/L at approximately 1 hour) (de Pascaul-Teresa et al. 2004). However, the expression of COX-2 mRNA in lymphocytes was unchanged by the consumption of high-quercetin onions compared with the low-quercetin group though this change occurred in-vitro and ex-vivo.

The volatile sample of freeze-dried onion sprout (extracted with dichloromethane), water sample I and water sample II exhibited anti-inflammatory activity with a dose-related response in the lipoxygenase inhibitor screening assay (Takahashi and Shibamoto 2008). However, the methanol sample did not show appreciable activity in either antioxidant or anti-inflammatory tests. An herbal fraction (ALC-02) from onion bulb inhibited histamine release and attenuated intracellular calcium levels in compound 48/80-induced rat peritoneal mast cells (Kaiser et al. 2009). It also prevented compound 48/80-mediated systemic anaphylaxis while lowering histamine levels in plasma. ALC-02 suppressed carrageenan-induced rat paw oedema. It inhibited eosinophil peroxidase activity and protein content in bronchoalveolar lavage fluid (BALF) of ovalbumin-challenged mice and also caused a substantial reduction in lipid peroxidation in BALF/lung tissue and augmented superoxide dismutase activity in lung tissue. ALC-02 suppressed erythrocytic lysis caused by Triton X-100. A significant quenching of 1,1-diphenyl-2-picrylhydrazyl radical by ALC-02 was observed.

Antilithogenic Activity

Dietary onion and garlic exerted antilithogenic influence by decreasing the cholesterol hypersecretion into bile and increasing the bile acid output thus decreasing the formation of lithogenic

bile in experimental mice (Vidyashankar et al. 2009, 2010b). Dietary garlic and onion, either raw or heat processed, regressed preformed cholesterol gallstone in mice up to 53–59 %, whereas the regression in the basal control diet group was only 10 %. The antilithogenic potency of garlic was decreased by its heat processing, but not in the case of onion. Biliary cholesterol was significantly decreased in garlic- and onion-fed animals. Biliary cholesterol saturation index and hydrophobicity index were significantly lowered by dietary garlic and onion. Serum and liver cholesterol levels were decreased by feeding onion and garlic during post-cholesterol gallstone induction period. Hepatic hydroxymethylglutaryl-coenzyme A reductase activity was increased after feeding garlic and onion, whereas activities of the cholesterol-degrading enzymes cholesterol-7α-hydroxylase and sterol-27-hydroxylase were increased in garlic- and onion-fed groups. These results indicated that feeding garlic and onion effectively accelerated the regression of preformed cholesterol gallstone by promoting cholesterol desaturation in bile. They also found that apart from the beneficial modulation of biliary cholesterol saturation index, onion and garlic influenced cholesterol nucleating and antinucleating protein factors that contributed to their antilithogenic potential (Vidyashankar et al. 2010a). Similar antilithogenic effects were found with fenugreek seed, onion and their combination administered as supplement to mice fed with a high-cholesterol diet (HCD) (0.5 %) for 10 weeks (Reddy and Srinivasan 2011). Fenugreek, onion and their combination reduced the incidence of cholesterol gallstones by 75 %, 27 % and 76 %, respectively, with attendant reduction in total cholesterol content by 38–42 %, 50–72 % and 61–80 % in the serum, liver and bile, respectively, in high-cholesterol lithogenic diet-fed mice. Increased accumulation of fat in the liver and inflammation of the gallbladder membrane produced by high-cholesterol diet were reduced by fenugreek, onion and their combination. The antilithogenic influence was highest with fenugreek alone, and the presence of onion along with it did not further increase this effect. There was also no additive effect of the two spices in the recovery of antioxidant molecules or in the antioxidant enzyme activities.

Neuroprotective Activity

In-vitro studies showed that the flavonoids extracted from onion could effectively penetrate the blood–brain barrier model established by co-culturing of brain microvascular endothelial cells and astrocytes (Dan et al. 2011). The onion flavonoids also showed marked inhibition on the H_2O_2-induced neuron cell apoptosis and DNA injury. Yang et al. (2012a) found that the protective effect against glutamate-induced neurotoxicity in HT22 cells was increased when treated with 25 μg/mL of fermented onion. The enhanced neuroprotective effect was also originated from the increased quercetin content caused by fermentation.

Pretreatment of animals with a methanolic extract of outer scales and edible onion portions markedly reduced cerebral infarct size and attenuated impairment in short-term memory and motor coordination (Shri and Singh Bora 2008). The protective effect of onion on ischaemia and reperfusion-induced cerebral injury was accompanied by a marked decrease in mitochondrial TBARS. Treatment with methanol extracts of outer scales of onion significantly prevented loss in body weight, decreased plasma glucose level and significantly ameliorated thermal hyperalgesia, TBARS, serum nitrite and GSH levels in neuropathic diabetic mice. This was postulated to be due to the higher content of phenolic compounds in outer scales (Bhanot and Shri 2010). Onion extract (OE) and its major component, quercetin, exerted neuroprotective effects on ischaemic neuronal damage from transient cerebral ischaemia in the gerbil hippocampus (Hwang et al. 2009). In the OE-treated ischaemic group, gliosis (activation of astrocytes and microglia) was attenuated in the hippocampal CA1region 4 days after ischaemia/reperfusion. In addition, treatment with OE and quercetin decreased protein levels of 4-hydroxy-2-nonenal (a marker for lipid peroxidation) in the ischaemic CA1region.

Hyun et al. (2013) demonstrated that onion extract attenuated brain ischaemia-induced oedema and blood–brain barrier (BBB) dysfunction in mouse middle cerebral artery occlusion model. Onion extract prevented brain oedema, BBB hyperpermeability and tight junction proteins disruption, possibly through its antioxidant effects. Their study suggested that onion extract may be a beneficial nutrient for the prevention of BBB function during brain ischaemia.

Hepatoprotective Activity

Studies showed that cadmium-induced oxidative damage in rat liver was amenable to attenuation by pretreatment of high dose of onion and moderate dose of garlic extracts possibly via reduced lipid peroxidation and enhanced antioxidant defence system (Obioha et al. 2009). Intraperitoneal injection of 15 mg/kg quercetin from onions exhibited significant protective effect on hepatocytes apoptosis in streptozotocin-induced diabetic rat (Bakhshaeshi et al. 2012). Quercetin also reduced malonaldehyde and aldehyde oxidase levels compared to untreated diabetic rats. Pretreatment of rats with onion extract protected against doxorubicin (DOX)-induced hepatotoxicity due to the antioxidant properties of onion extract (Mete et al. 2013). Further, onion treatment markedly reduced liver parenchymal necrosis and proliferation of biliary duct.

Renoprotective Activity

The study of Suru (2008) suggested that onion and garlic extracts may exert their protective effects against cadmium-induced nephrotoxicity in rats via reduction in renal lipid peroxidation and enhanced antioxidant defence. While treatment with high dose of onion extract exerted a significant dose-dependent restoration of the cadmium-induced decrease in antioxidant activities, treatment with high dose of garlic elicited a pro-oxidant effect, relative to their respective low dose. Oral pre-administration of onion extract prevented cadmium-induced renal dysfunction in rats by improving the antioxidant status in plasma and tissues and reducing the elevated MDA level in plasma (Ige et al. 2009).

Gavage administration of fresh onion juice to rats with renal failure as a result of infection by the protozoan parasite, *Toxoplasma gondii*, ameliorated the parasite-induced harmful effects by reducing the apoptosis of renal cells and increase in antioxidant activity (Gharadaghiet al. 2012).

Antispasmodic Activity

The furostanol saponins, tropeoside A1/A2 and tropeoside B1/B2, isolated from Tropea red onion bulb were found to possess antispasmodic activity in the guinea pig-isolated ileum; such an effect might support the traditional use of onion in the treatment of disturbances of the gastrointestinal tract (Correa et al. 2005).

Studies by Grman et al. (2011) found that aqueous garlic, onion and leek extracts released nitric oxide from S-nitrosoglutathione (GSNO) in the following order: garlic > onion > leek. Garlic extract (0.045 mg/mL) prolonged relaxation time of aortic rings induced by GSNO (50 nmol/L) and inhibited intracellular chloride channels. It was suggested that NO-releasing properties of the garlic, onion and leek extracts and their interaction with Cys and GSH were involved in NO-signalling pathway which contributed to some of its numerous beneficial biological effects.

CNS Antidepressant Activity

The results of an animal study suggested that onion exerted antidepressant-like activity in a behavioural model that acted independently of the hypothalamic–pituitary–adrenal axis (Sakakibara et al. 2008). Daily administration of onion powder at a dosage of 50 mg/kg of body weight/day for 14 days significantly reduced the immobility time in the forced swimming test without changing the motor dysfunction, indicating that the

daily consumption of onion exerted antidepressant-like activity. Onion powder (50 mg/kg) suppressed the increase in the turnover of dopaminergic activity.

Antimutagenic Activity

Water extracts of garlic, deodorised garlic powder and onions, but not leeks, were found to reduced the in-vitro formation of N-nitrosomorpholine (NMOR), a known liver carcinogen (Dion et al. 1997). Addition of increasing quantities (20, 40 and 80 mM) of S-allylcysteine (SAC), a water-soluble compound in processed garlic, depressed NMOR formation by 16 %, 27 % and 43 %, respectively. SAC and S-propyl cysteine were less effective than isomolar cysteine in reducing NMOR formation. The oil-soluble sulfur compounds diallyl disulfide (DADS), dipropyl disulfide and diallyl sulfide were ineffective inhibitors of NMOR generation. SAC and DADS reduced the mutagenicity of NMOR in *Salmonella typhimurium* TA100. SAC at 70 μmol/plate reduced the number of histidine revertants per plate by 51 %, whereas DADS at 0.12 mumol/plate reduced mutant colony number by 76 %. SAC and DADS were more effective than isomolar cysteine in reducing NMOR mutagenicity. The ability of sulfur compounds in garlic and onions to depress nitrosamine formation and bioactivation accorded with epidemiologic evidence that higher intake of *Allium* plants was associated with a reduction in the risks of some cancers.

After digestion, ethyl acetate extracts from white, yellow and red onions extracts showed antimutagenic activity (Shon et al. 2004). The ethyl acetate fraction of red onion peel showed dose-dependent antimutagenic activity by following the inhibition of tobacco-induced mutagenicity in *Salmonella typhimurium* strains (TA102) and hydroxyl radical-induced nicking in plasmid pUC18 DNA (Singh et al. 2009). Kim et al. (2013) found that pretreatment with onion peel extract significantly reduced human leucocyte DNA damage induced by H_2O_2 or 4-hydroxynonenal, indicating that it possessed antigenotoxic activity.

Antiosteoporotic Activity

One gram of onion added to the food of rats inhibited significantly bone resorption as assessed by the urinary excretion of tritium released from bone of 9-week-old rats prelabelled with tritiated tetracycline from weeks 1 to 6 (Wetli et al. 2005). The bone resorption-inhibiting compound was identified as γ-L-glutamyl-*trans*-*S*-1-propenyl-l-cysteine sulfoxide (GPCS). It has a molecular mass of 306 Da and inhibited dose dependently the resorption activity of osteoclasts, the minimal effective dose being approximately 2 mM. The water solution of onion crude powder decreased the osteoclastogenesis from co-cultures of bone marrow stromal cells and macrophage cells by inhibiting the receptor activator of nuclear factor kappa B ligand (RANKL)-induced ERK, p38 and NF-kappaB activation (Tang et al. 2009). However, it did not affect cell proliferation and differentiation of human-cultured osteoblasts. The data showed that onion powder may benefit bone through an anti-resorption effect on the osteoclasts. Young adult female Wistar rats fed with onion-enriched diet showed a lesser ovariectomy-induced bone loss in a dose-dependent manner and counteracted deterioration of biochemical properties (Huang et al. 2008). Onion-fed rats showed lower levels of serum calcium and osteocalcin, suggesting a downregulation of bone turnover. Onion group had significantly more trabecular number, less separated trabeculae and fewer osteoclasts and reduced the ovariectomy-induced decrease in bending load and bending energy.

Studies showed that quercetin in a collagen matrix had the effect of increasing new bone formation locally in rabbits and could be used as a bone graft material (Wong and Rabie 2008). A total of 556 % more new bone was present in defects grafted with quercetin in a collagen matrix than those grafted with a collagen matrix alone. No bone was formed in the passive control group. The results of studies by Tsuji et al. (2009) suggested that dietary quercetin inhibited bone loss without effect on the uterus in ovariectomised mice and did not act as a potent inhibitor of osteoclastogenesis or as a selective oestrogen

receptor modulator in-vivo. In-vitro in mouse monocyte/macrophage cell line RAW264.7 cells, quercetin and its conjugate, quercetin 3-*O*-β-D-glucuronide, dose dependently inhibited the receptor activator of nuclear factor kappa β ligand (RANKL)-induced osteoclast differentiation, and the RANKL-stimulated expression of osteoclast related genes was also inhibited by quercetin.

Wound/Scar Healing Activity

The C1 extract of onion was found to be rich in flavonoids, triterpenic acids, amino acids and compounds recognised for their beneficial effects in wound and scar healing and also had good antimicrobial activity (Tătărîngă et al. 2005). For onion (30 %w/w)-based gel ointments for wound healing, formula F1 was found to be most efficient in the membrane diffusion process, while formula F2 displayed good wound contracting ability (Gafiţanu et al. 2006).

Whiting and Guinea (1998) reported that the pain and inflammation of a man wounded at in the instep of the right foot by a blue-spotted stingray in the Northern Territory, Australia, was subdued when half an onion was bandaged onto the wound. After an hour, he was able to walk on it with joint stiffness. In a side-by-side, randomised, double-blinded, split-scar study of 24 patients with new surgical wounds, no statistically significant difference was found between the onion extract gel and a petrolatum-based emollient in improving the appearance and symptoms of new surgical scars (Chun et al. 2006). In a comparative prospective study involving 60 patients, topical onion extract in gel form improved hypertrophic and keloid scars via multiple mechanisms (Hosnuter et al. 2007). However, it was statistically ineffective in improving scar elevation and itching. The most effective therapeutic results were obtained when the silicone gel sheet treatment was combined with onion extract. Data from studies by Cho et al. (2010) indicated that onion extract and quercetin played a role in the anti-scar effect in skin by inhibition of fibroblast activities and upregulation of matrix metalloproteinase-1 expression, implying quercetin to be a promising material for reducing scar formation. In another study involving 60 subjects with symmetrical seborrheic keratoses at least 8 mm in diameter on the right and left upper chest, the application of the onion extract gel after surgical excision of lesions significantly improved scar softness, redness, texture and global appearance at the excision site at study weeks 4, 6 and 10 as assessed by the blinded investigator (Draelos 2008). In an open, randomised, controlled, comparative study of 27 patients, treatment with intralesional triamcinolone acetonide (TAC) alone and with onion extract were effective in the therapy of keloidal and hypertrophic scars (Koc et al. 2008). Combined with onion extract gel, intralesional TAC appears to be superior to TAC alone.

In an open-label, controlled, nonrandomised clinical trial of 15 patients, topical applications of a gel containing *Allium cepa*, pentaglycan and allantoin twice a day for 24 weeks appeared to be useful in reducing neoangiogenesis in hypertrophic scars and keloids, resulting in clinical improvement of skin lesions (Campanati et al. 2010). In a randomised, double-blinded, placebo-controlled study of 60 patients with hypertrophic scars after median sternotomy, the use of silicone derivative and onion extract gel was found to be safe and effective for the preventing the hypertrophic scarring (Jenwitheesuk et al. 2012). No adverse events were reported by any of the patients. Results of a 6-month prospective placebo-controlled study showed that application of onion extract in silicone derivative gel could significantly decrease the incidence of hypertrophic scar from median sternotomy wound from an open heart surgery in paediatric patients (4.3 years) (Wananukul et al. 2013). Keloid did not show statistically significant differences in both groups.

Ointments containing heparin, e.g. enoxaparin and onion extract, are popularly used in prevention and treatment of keloids and hypertrophic scars which result in abnormal wound healing (Pikuła et al. 2014). The therapeutic mechanism was found to be associated with the inhibition of proliferation, apoptosis and downregulation of β1 integrin expression in human fibroblasts. Almost

complete inhibition of cell proliferation was achieved by enoxaparin in 500 μg/mL concentration (91.5 % reduction). The onion extract at a concentration of 250 μg/mL also strongly inhibited the proliferation of cells (50.8 % reduction). Depending on concentration, enoxaparin and onion extract induced apoptosis (500 and 1,000 μg/mL, respectively) and, depending on concentration, downregulated the expression of β1 integrin on human fibroblasts.

Anti-ageing/Anti-photoageing Activity

Myricetin treatment reduced UVB-induced epidermal thickening of mouse skin and also suppressed UVB-induced matrix metalloproteinase-9 (MMP-9) protein expression and enzyme activity (Jung et al. 2010b). Overall, the results indicated that myricetin exerted potent anti-photoageing activity by suppressing UVB-induced Raf kinase activity and subsequent attenuation of UVB-induced phosphorylation of MEK and ERK in mouse skin. Topical treatment with myricetin inhibited repetitive UVB-induced neovascularisation in SKH-1 hairless mouse skin (Jung et al. 2010a). The induction of vascular endothelial growth factor, matrix metalloproteinase (MMP)-9 and MMP-13 expression by chronic UVB irradiation was significantly suppressed by myricetin treatment. Also, myricetin inhibited UVB-induced hypoxia-inducible factor-1alpha expression in mouse skin. The results indicated that myricetin suppressed UVB-induced angiogenesis by downregulating PI-3 kinase activity and subsequently attenuated the UVB-induced phosphorylation of Akt/p70(S6K) in mouse skin lysates.

Studies on antioxidant (DPPH assay) and anti-ageing (*Caenorhabditis elegans* lifespan assay) activities of onion flavonoids, quercetin, quercetin 3′-*O*-β-D-glucopyranoside (Q3′G) and quercetin 3-*O*-β-D-glucopyranoside-(4→1)-β-D-glucopyranoside (Q3M) found no direct correlation was found between antioxidative activity and anti-ageing activity (Xue et al. 2011). Quercetin showed the highest antioxidative activity, whereas Q3M showed the strongest anti-ageing activity among these flavonoids, which might be related to its high hydrophilicity.

Skin Whitening Activity

Dried onion skin showed potent melanin biosynthesis inhibitory activity in B16 melanoma cells (Arung et al. 2011a, b). Bioassay-guided fractionation led to the isolation of quercetin 3′-*O*-β-D-glucoside which inhibited melanin formation in B16 melanoma cells with an IC_{50} value of 38.8 μM and mushroom tyrosinase with an IC_{50} value of 6.5 μM. It also exhibited tyrosinase inhibitory activity using L-tyrosine or L-DOPA as a substrate, with IC_{50} values of 4.3 and 52.7 μM, respectively. In addition, it showed antioxidant activity of 3.04 μmol Trolox equivalents/mmol in the oxygen radical absorbance capacity assay. Dried onion skin and its flavonol could be useful for treating hyperpigmentation and for protecting against oxidative stress with potential for skin whitening cosmetics with antityrosinase activity.

Hair Growth Stimulating Activity

In a study of 23 patients, 16 males and 7 females with alopecia areata, topical treatment with crude onion juice applied twice daily for 2 months gave significantly higher results with regard to hair regrowth than did tap water (Sharquie and Al-Obaidi 2002).

Aphrodisiac/Fertility Enhancement Activity

Administration of fresh onion juice equivalent to 1 g/rat/day of fresh onion by gavage to Wistar male rats for 20 consecutive days significantly increased levels of luteinising hormone, but the levels of follicle-stimulating hormone did not differ between experimental and control groups (Khaki et al. 2009). The percentage of sperm viability and motility in both test groups (0.5 and 1 g) significantly increased, but the sperm concentration significantly

increased only in the group that received the high dose of freshly extracted onion juice. The study showed that freshly prepared onion juice significantly affected the sperm number, percentage of viability and motility. Oral administration of ethyl acetate fraction of onion to paroxetine-induced sexually impaired male rats for 7 days restored normal sexual dysfunction behaviour as evident from increased mount frequency, intromission frequency and ejaculatory frequency and reduced mount latency, intromission latency, ejaculatory latency and post-ejaculatory interval (Malviya et al. 2013). Allouh et al. (2014) demonstrated that fresh onion juice significantly reduced mount frequency and latency and increased the copulatory efficacy of sexually potent male rats and in those with paroxetine-induced sexual dysfunction by increasing serum testosterone levels.

Oral administration of onion and garlic extracts to rats successfully attenuated the adverse effects of cadmium-induced testicular damage and spermiotoxicity possibly reducing lipid peroxidation and increasing the antioxidant defence mechanism in rats (Ola-Mudathir et al. 2008). Cd caused a marked rise in testicular lipid peroxidation (LPO) and glutathione S-transferase (GST) levels and a decline in levels of glutathione (GSH), superoxide dismutase (SOD), catalase (CAT) and alkaline phosphatase (ALP). Cd intoxication significantly decreased epididymal sperm concentration and sperm progress motility and increased per cent total sperm abnormalities and live/dead count. Onion extract provided a dose-dependent protection. In a separate study, pretreatment of rats with crude onion extract ameliorated $CdSO_4$-induced alteration in testicular weight, sperm count, sperm motility and sperm morphology (Ige et al. 2012). Also, onion attenuated the derangement of lipid peroxidation profile in testicular tissues caused by $CdSO_4$ exposure.

Daily sperm production and total incidence of sperm abnormalities were significantly affected in mice injected with diesel exhaust particles (DEP) as compared with the vehicle group, but the total incidence of sperm abnormalities in the quercetin + DEP-treated mice was significantly reduced as compared with the DEP-treated mice (Izawa et al. 2008). The numbers of Sertoli cells were significantly decreased in DEP-treated mice as compared with the vehicle-treated mice, but the numbers of Sertoli cells were significantly increased in the quercetin and the onion + DEP-treated mice as compared with the DEP-treated mice. The results clearly indicated alleviative effects of quercetin and onion against male reproductive toxicity induced by DEP. Diesel exhaust particles (DEPs) are particulate matter from diesel exhaust that contain many toxic compounds, such as polyaromatic hydrocarbons (PAHs).

Hormonal Activity

Onion juice fed to rats produced (1) a testosterone-like effect as it increased the seminal vesicles and testicle weight in castrated and non-castrated animals, (2) an insulin-like action as it reduced blood sugar level in experimentally induced hyperglycaemic animals and (3) a growth hormonelike activity as it increased the growth rate in young rats (Sharaf 1967). Additionally, onion juice possessed an oxytocic action when tested, in-vitro, on the rat uterus at various stages of the sex cycle.

Antiparasitic Activity

Feeding *Biomphalaria alexandrina* with onion and garlic powder separately exerted some biological and biochemical changes that reduced the snails' fecundity that in turn disturbed the life cycle of *Schistosoma mansoni* parasite (Mantawy 2001; Mantawy and Mahmoud 2002). Glucose and glycogen were decreased significantly after feeding on onion and garlic. Also, phenol oxidase activity was highly significantly decreased after 2 and 7 days of feeding on garlic, while feeding on onion decreased the activity of the enzyme at all periods. Alkaline phosphatase was highly significantly reduced in haemolymph of snails that fed on either onion or garlic. Also, alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were highly significantly reduced in haemolymph of snails that were fed on onion, while those fed on garlic showed no change in ALT

activity and a high significant increase in AST activity. Total proteins were significantly decreased in haemolymph of all treated snails whereas variations in free amino acids contents were also observed. Administration of onion and garlic extract individually and mixed either with or without the currently used drug, praziquantel, to *Schistosoma mansoni*-infected mice significantly reduced parasite burden, hepatic and intestinal eggs and oogram count (Mantawy et al. 2011). The extracts ameliorated the increase in IgM, IgG, interleukins 2 and 6 (IL-2 and 6) and tumour necrosis factor (TNF-α) and catalase enzyme, accompanied with a decrease in GPX and SOD antioxidant enzyme activities caused by the parasite. Results of in-vitro studies indicated their strong biocidal effects against all stages of *Schistosoma mansoni* miracidia, schistosomula, cercaria and adult worms and also showed scavenging inhibitory effect on 2,2-diphenyl-1-picrylhydrazyl (DPPH) and nitric oxide (NO) (Mantawy et al. 2012).

Aqueous onion extract inhibited growth of five leishmanial strains in the promastigote stage in-vitro with IC_{100} and IC_{50} values of 1.25 mg/mL and 0.376 mg/mL, respectively (Saleehan et al. 2004). Aqueous onion extract was found to have inhibitory activity against *Leishmania major* promastigotes, parasite isolated from cutaneous leishmaniasis (Sadeghi-Nejad and Saki 2014).

Nigella sativa and *Allium cepa* oils exhibited anthelmintic effect in the rats infected with *Trichinella spiralis* infection and increased the production of antibodies generated during life cycle of the parasite (Abu El Ezz 2005). *A. cepa* oil showed more effectiveness than *N. sativa* on decline number of adult worms and muscle larvae when used as therapeutic treatment postinfection.

Feeding sheep for 8 days with onion extract and coconut combined with milk powder and/or polyethylene glycol (PEG) propylene carbonate stopped gastrointestinal nematodes and cestodes (Melhorn et al. 2011). In more recent studies, addition of micronised coconut and onion reduced worm (trematodes, cestodes and nematodes) load in horses and sheep and increased sheep body weight (Jatzlau et al. 2014). In the case of the horse treatment, the worm load decreased so enormously that mostly only single eggs or larvae were found in those horses that had accepted the onion–coconut food addition.

Antihyperuricaemic Activity

Oral administration of onion at 3.5 and 7.0 mg/kg/day for 7 days was able to reduce serum uric acid levels in potassium oxonate-induced hyperuricaemic rats with no significant effects on the level of this compound in the normal animals (Haidari et al. 2008b). Further, onion when tested in-vivo on rat liver homogeneities elicited significant inhibitory actions on the xanthine dehydrogenase (XDH) and xanthine oxidase (XO) activities. In another study, *Allium cepa* and quercetin treatments for 14 days significantly reduced serum uric acid levels of potassium oxonate-induced hyperuricaemic rats in a time-dependent manner (Haidari et al. 2008a). All treatments significantly inhibited hepatic xanthine oxidase/xanthine dehydrogenase activity. *Allium cepa* and quercetin treatments led also to a significant improvement in biomarkers of oxidative stress in hyperuricaemic rats.

Immunostimulating Activity

The consumption of onions resulted in significant reductions in plasma triacylglycerol; however, the reductions were most pronounced in pigs fed with destiny onions (−26 %) (Ostrowska et al. 2004). Total plasma cholesterol and LDL–HDL ratios were not significantly different. Onion supplementation, regardless of the variety, resulted in dose-dependent reductions in erythrocyte counts and Hb levels, while the white blood cell concentrations, particularly lymphocytes, were increased in pigs that consumed onions. It was concluded that dietary supplementation with raw brown onions has moderate lipid-modulating and immunostimulatory properties. Studies revealed that CD4 and total white blood cell (WBC) counts were significantly increased in a dose-dependent

manner in both onion- and garlic-treated rats when compared to the zero control (Mirabeau and Samson 2012). However, no significant effect was observed on these parameters when extracts were combined. The results from this study revealed the immune-boosting capabilities of onion and garlic, but underscored their synergistic activities. The pectic polysaccharide from immature onion stick showed in-vitro splenocyte, thymocyte as well as macrophage activations (Patra et al. 2013).

Suppression of Onion Lachrymatory Factor Synthase

The lachrymatory factor synthase gene in onion was suppressed by a single genetic transformation using RNA interference silencing (Eady et al. 2008). This reduced lachrymatory synthase activity by up to 1,544-fold, so that when wounded, the onions produced significantly reduced levels of tear-inducing lachrymatory factor. The researchers confirmed that silencing had shifted the *trans*-S-1-propenyl-L-cysteine sulfoxide breakdown pathway so that more 1-propenyl sulfenic acid was converted into di-1-propenyl thiosulfinate. A consequence of this raised thiosulfinate level was a marked increase in the downstream production of a nonenzymatically produced zwiebelane isomer and other volatile sulfur compounds, di-1-propenyl disulfide and 2-mercapto-3,4-dimethyl-2,3-dihydrothiophene, which had previously been reported in trace amounts or had not been detected in onion.

Drug Metabolising Activities

Consumption of onion induced cytochrome P450 (CYP)s enzymes CYP 1A and CYP 2B activities, while it decreased CYP 2E1 activity in rats (Teyssier et al. 2001). The same dietary treatment caused a slight increase of the total glutathione S-transferase (GST) phase II enzyme activity. The relative proportions of GST subunits were modified; GST Al/A2 subunits were increased, while GST A3/A5 and GST M2 subunits were decreased and GST M1 and P1 were not modified. Onion consumption also increased *p*-nitrophenol UDP-glucuronosyltransferase (UGT) phase II enzyme activity. Taken together, the results suggested that the decrease of CYP 2E1 and the increase of phase II enzymes by onion could afford protection against some carcinogens, while the decrease of some GST subunits could increase the genotoxic effects of other chemicals. The modulating effect of onion could be ascribed to alk(en)yl polysulfides and/or glycosides of flavonols, which were identified in the onion powder.

Anticataract Activity

Instillation of onion juice into the rat eyes was found to effectively prevent selenite-induced cataract formation (Javadzadeh et al. 2009). This effect was associated with increased total antioxidative level, glutathione peroxidase (GPX) and superoxide dismutase (SOD) activities in the lens.

Urease Inhibitory Activity

Quercetin 4′-*O*-β-D-glucopyranoside isolated from onion exhibited urease inhibition activity with an IC_{50} value of 190 μM (Shabana et al. 2010).

Protease Inhibitory Activity

Three protease inhibitors (OTI-1-3) with molecular masses of 7,370.2, 7,472.2 and 7,642.6 Da were purified from onion bulbs (Deshimaru et al. 2003). Based on amino acid composition and N-terminal sequence, OTI-1 and OTI-2 are the N-terminal truncated proteins of OTI-3. All the inhibitors were stable to heat and extreme pH. OTI-3 inhibited trypsin, chymotrypsin and plasmin.

Haematological Studies

The degree of haemolysis of albino Wistar rat erythrocyte was greater in the treatment group compared to control, and the percentage haemolysis was greater in blood samples with onion and garlic compared to the onion alone group (Salami et al. 2012). The same observation was made in the in-vitro study, but the degree of haemolysis was significantly higher in in-vitro than the in-vivo experiments. It was concluded that onion and garlic increase the osmotic fragility of red blood cells in albino rats.

Pharmacokinetic Studies

In a study of nine healthy ileostomy volunteers, supplementation of fried onions at breakfast (rich in quercetin glucosides) equivalent to 89 mg aglycone, pure quercetin rutinoside (the major quercetin compound in tea) equivalent to 100 mg aglycone or 100 mg pure quercetin aglycone, in random order, showed that humans absorbed appreciable amounts of quercetin and that absorption was enhanced by conjugation with glucose (Hollman et al. 1995). Mean excretion of quercetin or its conjugates in urine was 0.5 % of the amount absorbed; quercetin excretion in urine was negatively correlated with excretion in ileostomy effluent. The following metabolites of quercetin flavonols, 3,4-dihydroxyphenylacetic acid (homoprotocatechuic acid), metahydroxyphenylacetic acid and 4-hydroxy-3-methoxyphenylacetic acid (homovanillic acid), were detected in human urine after intake of food rich in quercetin like onion, apples and tea (Gross et al. 1996). The mean concentrations of 3,4-dihydroxyphenylacetic acid, metahydroxyphenylacetic acid and homovanillic acid in human urine samples were approximately 0.7, 4.8 and 2.8 μg/mL, respectively.

After consumption of lightly fried onion containing contain conjugates of quercetin and isorhamnetin, including quercetin 3,4 ′-di-*O*-β-glucoside, isorhamnetin 4′-*O*-β-glucoside and quercetin 4′-*O*-β-glucoside by human volunteers, it was found that onion flavonols were absorbed into the bloodstream as glucosides and minor structural differences affected markedly both the level of accumulation and the extent to which the conjugates were excreted (Aziz et al. 1998). In a randomised two-phase crossover supplementation trial of six healthy nonobese normocholesterolaemic female volunteers in the age range 20–44 years, a meal of fried onions and fried onions together with tomatoes led to transient decreases in biomarkers of oxidative stress, although the particular biomarkers affected differed (Boyle et al. 2000). Flavonoid glucosides (quercetin 3-glucoside and isorhamnetin 4-glucoside) were significantly elevated in plasma following ingestion of the onion meal, and the increases were associated with an increased resistance of lymphocyte DNA to DNA strand breakage. A significant decrease in the level of urinary 8-hydroxy-2′-deoxyguanosine was evident at 4 hours following ingestion of the onion meal. After the combined tomato and onion meal, only quercetin was detected in plasma. Endogenous base oxidation was decreased, but resistance to strand breakage was unchanged. There was no significant change in the excretion of urinary malondialdehyde following either meal. Following consumption of fried onions, five different glucuronides of quercetin could be identified in human plasma samples (Wittig et al. 2001). In contrast, neither the free flavonol nor the genuine glycoside could be detected in plasma. The major circulating compounds found in the plasma of four individuals after 1.5 hours after consumption of onions were identified as quercetin 3-glucuronide, quercetin 3′-methylquercetin 3-glucuronide and quercetin 3′-sulfate (Day et al. 2001).

Consumption of the dietary flavonoid quercetin had been reported to form conjugates with glucuronic acid, sulfate or methyl groups in human plasma (Janisch et al. 2004). The ability of these quercetin conjugates to inhibit Cu(II)-induced oxidation of human low-density lipoprotein was determined to be in the following order: quercetin 7-glucuronide > quercetin > quercetin 3-glucuronide = quercetin 3-glucoside > catechin > quercetin 4′-glucuronide > isorhamnetin

3-glucuronide > quercetin 3′-sulfate. Thus, the proposed products of small intestine metabolism (quercetin 7-glucuronide, quercetin 3-glucuronide) were more efficient antioxidants than subsequent liver metabolites (isorhamnetin 3-glucuronide, quercetin 3′-sulfate). Albumin-bound conjugates retained their property of protecting LDL from oxidation, although the order of efficacy was altered (quercetin 3′-sulfate > quercetin 7-glucuronide > quercetin 3-glucuronide > quercetin 4′-glucuronide = isorhamnetin 3-glucuronide). Kq values (concentration required to achieve 50 % quenching) for albumin binding, as assessed by fluorescence quenching of Trp214, were as follows: quercetin 3′-sulfate (approximately 4 μM) = quercetin > or = quercetin 7-glucuronide > quercetin 3-glucuronide = quercetin 3-glucoside > isorhamnetin 3-glucuronide > quercetin 4′-glucuronide (approximately 20 μM).

Twenty-three flavonols as a range of mixed sulfate, methyl, glucuronide and glucoside derivatives of quercetin were detected in the urine and blood plasma of six human volunteers 0–4 hours after ingestion of lightly fried red onions, rich in anthocyanins and flavonols (Mullen et al. 2004). The flavonoids quercetin 3-glucuronide, quercetin 3′-glucuronide, quercetin 4′-glucuronide, quercetin 3′-sulfate and isorhamnetin 3-glucuronide were detected in samples from all volunteers. Samples from one volunteer also contained trace amounts of quercetin 3,4′-diglucoside, quercetin 3-glucoside, isorhamnetin 3-glucoside and the aglycone quercetin. Despite a high dosage, neither anthocyanins nor anthocyanin metabolites accumulated in either plasma or urine in detectable quantities. After consumption of cooked onion, more than 80 % of quercetin metabolites were localised in the human plasma fraction containing concentrated serum albumin (Murota et al. 2007). Other lipoprotein fractions contained only small amounts of quercetin metabolites. Addition of quercetin 3-*O*-β-glucuronide to the lipoprotein-eliminated plasma fraction generated antioxidant activity against LDL oxidation in a dose-dependent manner. However, onion consumption failed to enhance the antioxidant activity of the lipoprotein-eliminated plasma fraction against LDL oxidation, probably because the amount of quercetin metabolites bound to albumin was less than the effective level in an ex-vivo study.

Wiczkowski et al. (2008) found that when provided along with dietary sources, quercetin aglycone was more bioavailable than its glucosides in humans. The maximum plasma quercetin concentration of 1.02 μmol/L was reached at 2.33 hours after shallot flesh consumption compared with 3.95 μmol/L at 2.78 hours after dry skin consumption. The area under the concentration-time curve after dry skin consumption was 47.23 μmol/hour/L and was significantly higher than that after shallot flesh intake (22.23 μmol/hour/L). In a study of eight healthy female and eight male volunteers, consumption of the onion powder led to faster absorption, higher concentration and greater bioavailability of quercetin glycosides as compared to consumption of apple peel powder (Lee and Michael 2012). No significant gender-related differences were observed in the absorption of quercetin, whereas significant gender-related differences in the elimination half-time (t(1/2)) were observed. In the onion powder, quercetin occurred as the quercetin 3,4′-*O*-glucoside and quercetin 4′-*O*-glucoside. The predominant forms of quercetin in apple peel included quercetin *O*-arabinoside, quercetin 3-*O*-galactoside, quercetin 3-*O*-glucoside and quercetin 3-*O*-rhamnoside.

Studies with radiolabeled quercetin 4′-glucoside in rats showed that more than 95 % of the absorbed radioactivity was in the form of >20 different methylated glucuronated and/or sulfated quercetin conjugates (Graf et al. 2005). Five hours after ingestion, the main radiolabeled metabolites were quercetin diglucuronides in the gut, liver and kidneys and glucuronyl sulfates of methylated quercetin in plasma. The main site of quercetin metabolism seemed to be the gastrointestinal tract. Quercetin metabolites may have a major influence on the gut mucosal epithelium and on colonic disease.

Pure quercetin aglycone was absorbed by the Caco-2 cells in higher concentrations than quercetin 3-glucoside (Boyer et al. 2004). Caco-2 cells treated with quercetin 3-glucoside accu-

mulated both quercetin 3-glucoside and quercetin. Caco-2 cells absorbed more onion quercetin aglycone than onion quercetin 3-glucoside, and the percentage of onion quercetin absorbed was greater than that of pure quercetin, most likely due to enzymatic hydrolysis of quercetin 3-glucoside and other quercetin glucosides found in the onion by the Caco-2 cells. An in-vitro anaerobic fermentation in rat caecal inoculums of onion-supplemented diet (10 % fructans) showed an increase in the production of total and individual (propionate, acetate and butyrate) short-chain fatty acids (SCFA) and a decrease in the pH of the caecal content compared to the control group (Pascoal et al. 2013). Additionally, onion-supplemented rats presented increases in the weight and moisture of the faeces, the moisture of the caecal content, the total weight of the cecum and the weight of the caecal wall. All parameters evaluated of rat diets showed that onion had a higher in-vitro fermentation than the CD control group as a consequence of the presence of fructans. The in-vitro results (increase in the production of SCFA and in the molar proportion of propionate and butyrate and decrease in the molar proportion of acetate and in pH) were in accord with the in-vivo caecum fermentation results, suggesting the feasibility of using in-vitro fermentation to predict possible effects of the fermentation of onion products.

Cycloalliin, an organosulfur compound found in garlic and onion, when administered intravenously at 50 mg/kg to rats, was rapidly eliminated from blood and excreted into urine, and its total recovery in urine was 97.8 % in 48 hours (Ichikawa et al. 2006). After oral administration, cycloalliin appeared rapidly in plasma. Orally administered cycloalliin was distributed in the heart, lung, liver, spleen and especially kidney. When administered orally at 50 mg/kg, cycloalliin was excreted into urine but not faeces. However, the total faecal excretion of (3*R*,5*S*)-5-methyl-1,4-thiazane-3-carboxylic acid was 67.3 % (value corrected for cycloalliin equivalents). In addition, no (3R,5S)-5-methyl-1,4-thiazane-3-carboxylic acid was detected in plasma (<0.1 μg/mL), and negligible amounts (1.0 %) were excreted into urine. In in-vitro experiments, cycloalliin was reduced to (3*R*,5*S*)-5-methyl-1,4-thiazane-3-carboxylic acid during anaerobic incubation with caecal contents of rats. The data indicated that the low bioavailability (3.73 % and 9.65 % at 25 and 50 mg/kg, respectively) of cycloalliin was due mainly to reduction to (3*R*,5*S*)-5-methyl-1,4-thiazane-3-carboxylic acid by the intestinal flora and also poor absorption in the upper gastrointestinal tract.

Toxicity Studies

Oral or intraperitoneal administration of low doses of onion (50 mg/kg) to rats had little effect on lung and liver tissues when compared to control animals (Thomson et al. 1998). In contrast, administration of high doses of onion (500 mg/kg) resulted in apparent histological changes in lung and liver tissues of rats. Intraperitoneal administration of the high dose of onion was more damaging to lung and liver tissue than oral administration and resulted in a 25 % rate of mortality in this treatment group.

Allergy Issues

A case of a 44-year-old woman with severe systemic reactions (intense itching, urticaria, confusion, blurred vision, transient loss of consciousness, sweating, tachycardia) after ingestion of raw or lightly cooked onion was reported by Arena et al. (2000). Unheated onion extract resulted positive in class 2, heated extract negative, demonstrating that this patient was different from similar clinical cases described in literature and had IgE antibodies recognising just thermolabile onion fraction. A case of a 45-year-old man with at least five episodes of severe, systemic urticaria/angioedema some minutes after eating raw onions during the previous few years was reported by Asero et al. (2001). The patient showed IgE reactivity to onion proteins at different molecular weights.

Roussos and Hirsch (2014) reported a rare case of a 32-year-old woman migraineur with

osmophobia and trigger to garlic and onion aroma. Upon exposure to onions and garlic aroma, she experienced a fortification spectra and visual entopia, followed by a biparietal, crushing level 10/10 headache, burning eyes and nose, lacrimation, perioral paresthesias, generalised pruritus, nausea, fatigue, sore throat, dysarthria, confusion, dyspnea, palpitations, presyncopal sensations, hand spasms, tongue soreness, neck pain, phonophobia and photophobia. The patient also experienced chemosensory complaints: dysosmias every few months, phantosmias of food or cleaning products every month for a minute of level 5/10 intensity, palinosmia of onion or garlic odour for 30 minutes after exposure and metallic parageusia after eating with metal utensils. Allergy skin test was positive for garlic and onion. Nose plug and counter stimulation with peppermint prevented the onset of headaches and associated symptoms.

Traditional Medicinal Uses

Onion bulb is anthelmintic, anti-inflammatory, antiseptic, antispasmodic, carminative, diuretic, expectorant, febrifuge, hypoglycaemic, hypotensive, lithontriptic, stomachic and tonic (Grieve 1971; Lust 1974; Chiej 1984). Onion and garlic rich in several phytonutrients are recognised as important elements of the Mediterranean diet but are also used in the treatment and prevention of a number of diseases, including cancer, coronary heart disease, obesity, hypercholesterolaemia, diabetes type 2, hypertension, cataract, microbial infections and disturbances of the gastrointestinal tract (e.g. colic pain, flatulent colic and dyspepsia) because of their hypocholesterolaemic, hypolipidaemic, antihypertensive, antidiabetic, antibiotic, antithrombotic, antiasthmatic and anti-hyperhomocysteinaemia effects, and to possess many other biological activities including antimicrobial, antioxidant, anticarcinogenic, antimutagenic, antiasthmatic, immunomodulatory and prebiotic activities (Kendler 1987; Augusti 1996; Bianchini and Vaino 2001; Griffiths et al. 2002; Lanzotti 2006; Corzo-Martínez et al. 2007). Garlic and onion have been used as medicinal agents for thousands of years (Ali et al. 2000). Both garlic and onion had been shown to have applications as antimicrobial, antithrombotic, antitumour, hypolipidaemic, antiarthritic and hypoglycaemic agents. Historically, *Allium* crops have been used to treat a wide range of ailments, but the most prominent has been cardiovascular disease (Block 1992). In the Errachidia province in southeastern Morocco, *A. cepa* is one of several plants used to treat diabetes and hypertension (Tahraoui et al. 2007). *Allium cepa* is used for chilblains and to remove thorns and splinters in traditional phytotherapy in the Marche, Abruzzo and Latium regions in Central Italy Guarrera (2005). Fenugreek, garlic and onion are recommended in Persian folklore medicine as beneficial in the treatment of diabetes (Jelodar et al. 2005).

When used regularly in the diet, onions offset tendencies towards angina, arteriosclerosis and heart attack and also useful in preventing oral infection and tooth decay (Chevallier 1996). Baked onions can be used as a poultice to remove pus from sores and warmed onion juice can be used as eardrop to treat earache (Chevallier 1996). Fresh onion juice is a very useful first aid treatment for bee and wasp stings, bites, grazes or fungal skin complaints (Chiej 1984; Allardice 1993). It also aids in the formation of scar tissue on wounds, thus speeding up the healing process, and has been used as a cosmetic to remove freckles (Chiej 1984). Onion juice rubbed into the skin is said to promote the growth of hair and to be a remedy for baldness (Chiej 1984; Chevallier 1996). Bulbs of red onion cultivars are used to make a homeopathic remedy particularly in the treatment of people whose symptoms include running eyes and nose (Castro 1996). The German Commission E Monographs (1998), a therapeutic guide to herbal medicine, approve *Allium cepa* onion for appetite loss, arteriosclerosis, dyspeptic complaints, fevers and colds, cough/bronchitis, hypertension, tendency to infection, inflammation of mouth and pharynx and common cold.

Other Uses

Onion plant and bulb contain phytochemicals that exhibit pesticidal activities against plant and animal insect pest and phytopathogens. The growing plant is reported to repel insects and moles (Allradice 1993). The juice of the plant is used as a moth repellent and can also be rubbed onto the skin to repel insects (Chiej 1984). Onion water extract is said to the resistance of other plants to diseases and parasites (Allardice 1993).

Allicepin, an antifungal peptide isolated from onion bulb, exerted an inhibitory activity on mycelial growth in several fungal species including *Botrytis cinerea*, *Fusarium oxysporum*, *Mycosphaerella arachidicola* and *Physalospora piricola* (Wang and Ng 2004). Antifungal activity of three onion saponins increased with their concentration and varied with the following rank: ceposide B > ceposide A = ceposide C (Lanzotti et al. 2011). A significant synergism in the antifungal activity of the three ceposides in combination was observed against *Botrytis cinerea* and *Trichoderma atroviride*. In contrast, *Fusarium oxysporum* f. sp. *lycopersici*, *Sclerotium cepivorum* and *Rhizoctonia solani* were very little affected by saponins. Six *Fusarium*-inoculated shallot (*Allium cepa* var. *aggregatum*) strains seemed to be adequately resistant against disease, and the levels of resistance may be related to the saponin content in the bulb tissues (Vu et al. 2013). The n-butanol extract of shallot (*Allium cepa* Aggregatum group) basal plates and roots showed antifungal activity against plant pathogenic fungi (Teshima et al. 2013). Inoculation experiments showed that alliospiroside A isolated from shallots protected strawberry plants against *Colletotrichum gloeosporioides* indicating it had the potential to control anthracnose of the plant.

Onion oil exhibited acaricidal effect on all stages of *Boophilus annulatus* hard tick at concentrations higher than 5 % (Aboelhadid et al. 2013). The 10 and 20 % onion oil in ethanol and methanol alcohols killed 76–86 % of the adult ticks within 72 hours postapplication. While, all larvae died within 24 hours post subjected to these two concentrations. These concentrations (10 and 20 %) of onion oil in water killed 56–80 % of the treated ticks. Moreover, 10 % aqueous solution of onion oil prevented hatching of embryonated eggs.

The plant juice can be used as a rust preventative on metals and as a polish for copper and glass (Chiej 1984). A yellow–brown dye is obtained from the outer skin of the bulbs (Gare 1974). Polyphenols could be recovered from onion solid wastes under optimal conditions (60 % ethanol, pH 2 and 4.2 hours) with a predicted theoretical yield of 9,342 mg gallic acid equivalents per 100 g dry weight (Kiassos et al. 2009). The principal phytochemicals recovered were quercetin 3,4′-diglucoside, quercetin 4′-glucoside and quercetin.

Comments

Hanelt (1990) broadly divided *Allium cepa* into the common onion and Aggregatum groups. Fritsch and Friesen (2002) divided A. *cepa* into three groups: common onion group, Aggregatum group and an ever-ready onion group. The last group can be distinguished from the other two groups by its prolific vegetative growth and lack of a dormant period. Bulbs or leaves are used mainly as a salad onion and can be harvested at all times of the year.

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Allium chinense

Scientific Name

***Allium chinense* G. Don**

Synonyms

Allium bakeri Regel, *Allium bodinieri* H. Léveillé and Vaniot, *Allium exsertum* (Lindl.) Baker (illeg.), *Allium exsertum* G. Don, *Allium martini* H. Léveillé and Vaniot, *Allium splendens* Miq. (illeg.), *Allium triquetrum* Lour., *Caloscordum exsertum* (G. Don) Herb

Family

Amaryllidaceae

Common/English Names

Baker's Garlic, Chinese Onion, Chinese Scallion, Chinese Shallots, Japanese Scallion, Kiangsi Scallion, Kiangsi Shallot, Oriental Onion, Rakkyo, Small Angled Chives

Vernacular Names

Arabic: Tum El-Khabazeen
Chinese: Cong Ying Xie, Hsieh, Xie-Tou, Hsieh-Tou, Jiao Tou, Ku Jiao, Qiao Tou Tsung Tao, Xie, Ying Xie
Czech: Česnek Rakijo
Danish: Rakkyo, Rakkyoløg
Estonian: Rakkiolauk
Finnish: Valkoruohosipuli
French: Échalote Chinoise, Rakkyo
Hebrew: Shum sini
Hungarian: Iyabasi
Indonesia: Longkio, Bawang Kucai (Java) Bawang Ganda (Malay)
Japanese: Rakkyō, Rakkyou, Esharetto, Hana Rakkyou, Shima Rakkyou, Tama Rakkyou, Rakky
Korean: Yeom Kyo
Malaysia: Lokyo
Polish: Szczypiorek chiński
Portuguese: Chalota Chinesa
Spanish: Chalote Chinesa, Cebollino De La China, Cebolinha para picles
Swedish: Rakkyolök
Thailand: Mee Yoi (Northern), Krathiam-Chin, Hom-Prang, Hom-Paenyuak
Vietnamese: Kieu, Củ Kiệu

Origin/Distribution

Rakkyo occurs spontaneously in Central and Eastern China (in Anhui, Fujian, Guangdong, Guangxi, Guizhou, Hainan, Henan, Hubei, Hunan, Jiangxi and Zhejiang provinces) and in

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Japan, Korea, Russia and Mongolia. It is widely cultivated in China and Japan. It is also cultivated in Southeast Asia (Cambodia, Laos, Vietnam, Thailand, Myanmar, Malaysia, Singapore and Indonesia) and introduced with oriental emigrants from this region into further areas, e.g. the United States (Hawaii, California) and Cuba.

Agroecology

Rakkyo is well adapted to the temperate and subtropical conditions in latitude 30–40° N and S, in the temperature range of 15–35 °C. The crop prefers well-drained, friable and moderately fertile soils such as sandy loams and thrives in full sun. Too fertile soil such as the volcanic ash results in large and soft bulbs and a decrease in market value.

Edible Plant Parts and Uses

The bulbs and leaves are edible raw or cooked (Read 1982; Kunkel 1984; Facciola 1990; Larkcom 1991).

Bulbs are used raw or fried mixed with other vegetables in Indonesia. The bulbs are widely used as sweet or sour pickles after steeping in salt for several days. In Japan, they are used mainly in pickles as side dishes, often eaten with Japanese curry. Rakkyo is used as a pickled meal during Vietnamese New Year – Tet celebrations. Flowers and young seedpods are also edible raw, used as a garnish on salads.

Botany

A biennial clustered, caespitose bulbous herb up to 63 cm tall with adventitious roots (Plates 1, 2, 3, and 4). Bulbs are narrowly ovoid to ellipsoid, 1–4 cm in diameter with a white, membranous coat which is often tinged with reddish purple and gradually merging into the leaf blades at the top (Plates 1, 2, 3, 4, and 5). Leaves are hollow but the scape is solid. Leaves are distichous, cylindrical, hollow, 20–50 cm by 1–5 mm and 3–5 angled (Plates 1, 2, 3, and 4). Scape is lateral, 20–40 cm, terete and solid covered with leaf sheaths only at the base. Inflorescence consists of

Plate 1 Clump of rakkyo plant

Plate 2 Rakkyo plant habit

Plate 3 Small rakkyo bulbs with adventitious roots

Plate 4 Rakkyo with bulbs, pseudostems and leaves

Plate 5 Rakkyo bulbs

a hemispheric umbel with 6–30 lax flowers with two-lobed persistent spathe. Flowers are campanulate, purplish with six tepals arranged in two whorls, six stamens and a pistil longer than the tepals. Filaments equal, 1.5 × as long as tepals, connate at base and adnate to tepals; outer ones subulate; inner ones broadened at base, one-toothed on each side. The ovary is obovoid–globose, with concave nectaries covered by hoodlike projections at the base. Style exserted.

Nutritive/Medicinal Properties

Nutrients

Rakkyo bulb was reported to contain the following nutrient composition (Leung et al. 1972): energy 109 kcal, moisture 70.1 g, protein 0.8 g, fat 0.1 g, total carbohydrate 27.7 g, dietary fibre 0.4 g, ash 1.3 g, calcium 26 mg, phosphorus 9 mg, iron 0.6 mg, thiamine 0.5 mg, riboflavin 0.3 mg, niacin 0.7 mg and ascorbic acid 2 mg.

Phytochemicals

Infrared spectra and relative retention volumes were used to confirm the production of asymmetric disulfides, methyl-allyl, methyl-*n*-propyl and allyl-*n* propyl compounds by *Allium chinense* (Jacobsen et al. 1964). The compounds identified from the neutral fraction of *A. chinense* volatile oil included sulfides, thiolanes, alcohols, aldehydes, ketones, furanones and others (Kameoka et al. 1984). Among the sulfur compounds, dipropyl disulfide comprised *ca* 30 % of rakkyo oil. Rakkyo oil was characterised by a large amount of 2,3-dihydro-2-hexyl-5-methylfuran-3-one (*ca* 20 %) 2,3-dihydro-2-hexyl-5-methylfuran-3-one (*ca* 20 %).

N-(*p-trans*-coumaroyl)tyramine and *N*-(*p-cis*-coumaroyl)tyramine, lunularic acid and *p*-coumaric acid were isolated from the bulb of *Allium chinense* (Goda et al. 1987). Adenosine, guanosine and tryptophan, as well as β-sitosterol β-D-glucoside, were isolated from the n-butanol-soluble fraction of Xiebai (rakkyo bulbs) (Okuyama et al. 1989). From bulbs of *Allium chinense*, a new furostanol glycoside, named chinenoside I, and its structure were established to be 26-*O*-β-glucopyranosyl 3β, 22, 26-trihydroxy-25(R)-5α-furostan-6-one 3-*O*-β-xylopyranosyl(1→4)[α-arabinopyranosyl(1→6)] β-glucopyranoside (Matsuura et al. 1989). Two furostanol saponins, named chinenosides II and III, were isolated along with seven known compounds, from *Allium chinense* bulbs (Peng et al. 1996a). The structures of chinenosides II and III were determined to be 26-*O*-β-glucopyranosyl 3,26-dihydroxy-(25*R*)-5 α-furost-20(22) -en-6-one 3-*O*-β-xylopyranosyl-(1→4)-[alpha-arbinopyranosyl(1→6)]-β-glucopyranoside and 26-*O*-β-glucopyranosyl 3 β,26-dihydroxy-(25*R*)-5 α-furost-20 (22)-en-6-one 3-*O*-α-arabinopyranosyl (1→6)-β-glucopyranoside, respectively. Two new furostanol saponins, chinenoside IV and V, were

isolated from *A. chinense* bulbs, and their structures elucidated as 26-*O*-β-glucopyranosyl-3β,26-dihydroxy-23-hydroxymethyl-25(R)-5α-furost-20(22)-en-6-one3-*O*-β-xylopyranosyl(1→4)-[α-arabinopyranosyl(1→6)]-β-glucopyranoside and that of 2 to be 26-*O*-β-glucopyranosyl-3β, 26-dihydroxy-23-hydroxymethyl-25-(R)-5α-furost-20(22)-en-6-one 3-*O*-α-arabinopyranosyl (1→6)-β-glucopyranoside, respectively (Peng et al. 1996b; Peng and Yao 1996). Both chinenosides IV and V may be the hydroxymethylation of chinenosides II and III in the plant by hydroxymethylase.

Six compounds were isolated from the anticoagulation and anticancer fractions of *Allium chinense* bulbs (Jiang et al. 1998). Their structures were established as (25*R*, *S*)-5 α-spirostane-3 β-ol 3-*O*-(β-D-glucopyranosyl-(1→2)-[β-D-glucopyranosyl-(1→3)]-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside); (25*R*, *S*)-5 α-spirostane-3 β-ol 3-*O*-(β-D-glucopyranosyl (1→2)-[β-D-glucopyranosyl-(1→3)](6-acetyl-β-D-glucopyranosyl)-(1→4)-β-D-galactopyranoside); (25*R*, *S*)-5 α-spirostane-2 α, 3β-diol 3-*O*-(β-D-glucopyranosyl-(1→2)-*O*-β-D-glucopyranosyl-(1→4)-β-D-galactopyranoside); (25*S*)-24-*O*-β-D-glucopyranosyl-3β,24β-dihydroxy-5α-spirost-3-*O*-α-arabinopyranosyl-(1→6)-β-D-glucopyranoside (chinenoside VI), chinenoside II and 2,3,4,9-tetrahydro-1-methyl-1H-pyrido [3,4-b] indole-3-carboxylic acid. Two saponins, xiebai-saponin I (laxogenin 3-*O*-β-xylopyranosyl (1→4)-[α-arabinopyranosyl (1→6)]-β-glucopyranoside) and laxogenin 3-*O*-α-arabinopyranosyl (1→6)-β-glucopyranoside, and the aglycone, laxogenin, together with two chalcones, isoliquiritigenin and isoliquiritigenin-4-*O*-glucoside, and β-sitosterol glucoside were isolated from the Chinese crude drug 'Xiebai', the bulbs of *Allium chinense* (Baba et al. 2000).

Antiplatelet Aggregating Activity

N-(*p-trans*-coumaroyl)tyramine and *N*-(*p-cis*-coumaroyl)tyramine, lunularic acid and *p*-coumaric acid, isolated from *Allium chinense* bulbs, were found to be inhibitors of prostaglandin(PG) and thromboxane synthetases (Goda et al. 1987). These compounds that inhibited prostaglandin biosynthesis also showed significant inhibitory effects on platelet aggregation induced by arachidonic acid and collagen. Of the compounds isolated from rakkyo bulbs, adenosine showed a significant inhibitory activity against both the primary and secondary wave aggregation of human platelet induced by 2 μM ADP, whereas guanosine and tryptophan and β-sitosterol β-D-glucoside showed no or very low inhibitory effects (Okuyama et al. 1989). Of the derivatives of adenosine and guanosine, adenosine 2′-monophosphate, adenosine 5′-monophosphate, adenosine triphosphate and guanylyl(3′→5′)adenosine also inhibited the primary and secondary wave aggregation with a dose-dependent response but not guanosine 3′-monophosphate and guanosine 5′-monophosphate. Steroidal saponins from *A. chinense* bulb, chinenoside II and II, exhibited fibrinolysis promoting activity with IC 50 of 14 and 13 mg/mL, respectively, while laxogenin 3-*O*-α-arabinopyranosyl(1→6)-β-glucopyranoside or laxoside had blood coagulation inhibitory effect with IC_{50} of 3.4 mg/mL (Peng and Yao 1996). Adenosine exhibited both platelet aggregation inhibitory effect and blood coagulation effect with IC_{50} of 1.87 and 25 mg/gmL, respectively.

Six compounds were isolated from the anticoagulation and anticancer fractions of *Allium chinense* bulbs (Jiang et al. 1998).

Cardiotonic/Cardioprotective Activity

The saponin fraction prepared from the methanolic extract of *Allium chinense* bulbs exhibited inhibitory activities on cyclic AMP phosphodiesterase (cAMP PDE) (43.5 %) and Na^+/K^+ ATPase (59.3 %) at a sample concentration of 100 μg/mL, respectively (Kuroda et al. 1995). The compounds isolated from the extract, (25*R*,S)-5 α-spirostan-3β-ol tetrasaccharide, showed inhibitory activities on both cAMP PDE and Na^+/K^+ ATPase, while (25*R*)-3β-hydroxy-5α-spirostan-6-one di- and trisaccharides inhibited only cAMP PDE.

Pretreatment of cultured rat cardiac H9C2 cells with *A. chinense* steroids 24 hours before exposure to 0.2 mm hydrogen peroxide markedly attenuated the cellular injury induced by H_2O_2 (Ren et al. 2010). H_2O_2-elevated lipid peroxidation and increase in intracellular free calcium concentration and the decreased cell viability were reverted by *A. chinense* steroids.

Anticancer Activity

Six compounds were isolated from the anticoagulation and anticancer fractions of *Allium chinense* bulbs (Jiang et al. 1998). Chalcones isolated from *A. chinense* bulbs, isoliquiritigenin and isoliquiritigenin 4-*O*-glucoside, exhibited potential inhibitory activity on 12-*O*-tetradecanoylphorbol-13-acetate (TPA)-stimulated 32Pi-incorporation into phospholipids of HeLa cells (Baba et al. 2000). Laxogenin showed marked inhibitory activity (82.1 %) at high dose (100 ug/mL), and isoliquiritigenin showed 100 % inhibition at 50 ug/mL, while the two saponins xiebai-saponin I and laxogenin 3-*O*-α-arabinopyranosyl(1→6)-β-glucopyranoside showed strong cytotoxicity to HeLa cells at the same dose. Oral administration of laxogenin reduced the average number of tumours per mouse (75.6 % inhibition) in two-stage murine lung carcinogenesis.

Antifungal Activity

Allium plants including *A. chinense* possessed antifungal activity, with garlic showing the lowest MFC (minimal fungicidal concentration) (Yin and Tsao 1999). With the exception of scallion, the inhibitory effect of *Allium* plants against *Aspergillus niger*, *A. flavus and A. fumigatus* decreased with increasing incubation and heating temperature. Acetic acid treatments increased the inhibitory effect for all plants against the three fungi, and there was no significant difference in this effect among the three pH (2, 4, 6) treatments investigated. The combination of acetic acid plus *Allium* plants was found to be an effective way to inhibit fungal growth.

Traditional Medicinal Uses

Rakkyo plant is astringent, carminative and expectorant and is used in the treatment of stuffiness sensation and pain in the chest, angina pectoris, pleurisy, bronchitis, diarrhoea and tenesmus in cases of dysentery (Yeung 1985).

Allium chinense is used as a folk medicine in tonics to help the intestines and as a stomachic (Duke 1992).

Other Uses

The juice of the plant is used as a moth repellent. The whole plant is said to repel insects and moles (Riotte 1978).

Comments

Several cultivars are being cultivated in China and Japan. In Japan, Tama rakkyo is a small bulb group with 1–25, and the bulbs are ellipsoidal, soft and firm necked; the Rakuda is a large bulb group with 6–9 bulbs per cluster, ellipsoidal with a long neck.

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Allium sativum

Scientific Name

***Allium sativum* L.**

Synonyms

Allium arenarium Sadler ex Rchb. (inval.), *Allium controversum* Schrad. ex Willd., *Allium longicuspis* Regel, *Allium ophioscorodon* Link, *Allium pekinense* Prokh., *Allium sativum* var. *controversum* (Schrad. ex Willd.) Nyman, *Allium sativum* subsp. *controversum* (Schrad. ex Willd.) K. Richt., *Allium sativum* subsp. *ophioscorodon* (Link) Schübl. & G. Martens, *Allium sativum* var. *ophioscorodon* (Link) Döll, *Allium sativum* var. *pekinense* (Prokh.) F. Maek., *Allium sativum* f. *pekinense* (Prokh.) Makino, *Allium sativum* var. *subrotundum* Gren. & Godr., *Allium sativum* subsp. *subrotundum* (Gren. & Godr.) K. Richt., *Allium scorodoprasum* var. *viviparum* Regel, *Allium scorodoprasum* subsp. *viviparum* (Regel) K. Richt., *Porrum ophioscorodon* (Link) Rchb., *Porrum sativum* (L.) Rchb. (illeg.)

Family

Amaryllidaceae

Common/English Names

American Field Garlic, American Wild Garlic, British Field Garlic, British Wild Garlic, Field Garlic, Garlic, Nectar Of The Gods, Poor Mans Treacle, Rocambole, Sand Leek, Stinking Rose, Wild Garlic

Vernacular Names

Albanian: Hudhër E Rëndomtë, Hudhra
Arabic: Ail, Alalhoum Alho, Faom, Fom, Fum, Saum, Som, Somu, Soom, Soom-Ul-Haiya, Sum, Taum, Thoum, Tum, Thumu, Tiryaqe
Aramaic: Skoradon, Tum
Armenian: Sekhdor, Sxtor
Austria: Knoblauch
Azeri: Sarimsaq
Basque: Baratzuri, Barahatz, Baratxuri, Berakatz
Belarusian: Časnok
Belgium: Knoflook
Brazil: Alho, Alho-Bravo, Alho-Comum, Alho-Hortense (Portuguese)
Breton: Kignen
Bulgarian: Chesnov Luk, Chesun
Burmese: Chyet Thon Phew
Chinese: Da Suan, Hu, Hu Suan, Suan, Suan Miao, Suan Tai, Taai Suan

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Coptic: Shjen, Skorton
Croatian: Bijeli Luk, Češnjak
Czech: Česnek Kuchyňský, Česnek Kuchyňský Pravý, Česnek Setý
Danish: Hvidløg, Slangehvidløg
Dutch: Knoflook
Estonian: Küüslauk
Esperanto: Ajlo
Finnish: Valkosipuli
French: Ail, Ail Ordinaire, Ail Blanc, Ail Commun, Ail Cultivé, Ail De Printemps, Ail Sans Bâton, Ail Rose Sans Bâton
Frisian: Knyflok
Georgian: Niori
German: Alterswurzel, Gemeine Knoblauch, Knoblauch, Knofel, Knuflauk, Knuflook, Knöblich, Stinkerzwiebel
Gaelic: Gairgean
Greek: Skorda, Skordo, Skordon, Skortho
Hausa: Tafarnuwa
Hebrew: Shoum, Shum
Hungarian: Fokhagyma
Icelandic: Hvítlaukur
India: Nohoru, Rosun (Assamese), Lasuna, Rasun (Bengali), Sambram Gufut, Chambram Gufur (Bodo), Lonumedhu (Dhivehi), Thom (Dogri), Lasan, Lassun (Gujarati), Lahasun, Lahsan, Lahsun, Lasan, Lassun, Lasun, Lehann (Hindi), Belluli, Bellulli, Billuci, Jawari Gadde (Kannada), Rynsun (Khasi), Lasun (Maithili),Nelluthulli, Poondu, Vellulli (Malayalam), Chanam (Manipuri), Lasoon, Lasun, Lasunas (Marathi), Purunvar (Mizo), Rasuna (Oriya), Lasan, Lasun (Punjabi), Arishtha, Bhutabhna, Bhutagna, Dirghapatraka, Grinjana, Grnjana, Hana, Katukanda, Lashuna, Lasuna, Lasunah, Maha-Ushadha, Mahakanda, Mahausa, Mahusudha, Mlecchakanda, Mlecha-Gandha, Rahuchhishta, Rahutsrishta, Rasona, Rasonah, Rasonaka, Rasonam, Ugragandha, Ulli, Vatari, Yavanasta, Yavaneshta, Yavanesta (Sanskrit), Acanam, Acanapanni, Acanapputu, Accanam, Acunam, Acunan, Acunapputu, Acuram, Amirtai, Araconam, Araipavanati, Arakacam, Arakacappuntu, Arital, Arittam, Arittampokki, Arittampokkipputu, Attankal, Cavukkiriya, Cavukkiriyacceti, Cocanam, Cocanapputu, Corutca, Cunakam, Cunakapputu, Cunam, Eripuntu, Ilacunam, Ilacunam, Iletitacceti, Iletitam, Iracanai, Iracanam, Iracanappuntu, Iraconakam, Iraconam, Iraconopi, Iracunam, Irecan, Irecani, Irecapputu, Kalinkam, Kantakam, Kantam, Katukantam, Kautatam, Kayam, Kirancam, Kirancanam, Kulamarccam, Kutiraippallan, Lacunam, Makorakattam, Malacanati, Matalam, Matamatu, Matamatupputu, Matukiyakentam, Mileccakantakam, Mileccakantam, Nattotarici, Nicciyam, Paccainirulli, Palantu, Poondu, Pundu, Puntu, Raconakam, Raconam, Racunam, Racunapputu, Tellulli, Temekavitayam, Tiri, Tiripuravanitacceti, Tiripuravanitam, Uccatai, Ukkirakantam, Ulli, Ulli-Poondu, Ulli, Ulliccuvetam, Ullipoondu, Ullippuntu, Ullipputu, Umiyarpuntu, Umiyarputu, Vacikaram, Vacikarapputu, Vacu, Vallaipundu, Vellai-P-Puntu, Vellai-Poondu, Vellaippundu, Vellaippuntu, Vellaipputu, Vellaipundu, Vellaipuntu, Vellaivenkayam, Vellapundu, Vellulli, Velvankayam, Velvenkayam, Venkavali, Venkaveli, Vetpuntu, Virutalam, Vullay Poondoo (Tamil), Tellagadda, Tellapya, Thellagaddalu, Thellavayalu, Vellipayalu, Velluli, Vellulli, Vellullitellagadda (Telugu), Bellulli (Tulu), Aghlees, Awqariyo Saqardeen, Lahasan, Lahsan, Lehsan, Lehsun, Seer (Urdu)
Indonesia: Bhabang Poté (Madurese), Bawang Putih (Malay), Bawang Bodas (Sundanese)
Irish: Gairleog
Italian: Agilo, Aglio, Agilo Domestico
Japanese: Gaarikku, Nin-Niku
Kashmiri: Romahan
Kazakh: Sarimsaq
Khmer: Khtüm Sââ
Korean: Kallik, Ma Nul
Laotian: Kath'ièm, Pak Thiam, Van Mahakan
Latvian: Ķiploki
Lithuanian: Česnakas
Macedonian: Luk
Malaysia: Bawang Putih
Maltese: Tewm
Mongolian: Sarimsag, Sarmis
Nepal: Lasun (Nepali), Lava, Labha (Nepalbhasa)
Norwegian: Hvitløk, Kvitlauk
Papiamento: Konofló
Papua New Guinea: Galik

Persian: Seer, Sir
Philippines: Ahos, Ahus (Bisaya), Baung, Bawang (Tagalog)
Polish: Czosnek, Czosnek Pospolity
Portuguese: Alho, Alho Comum
Provençal: Aiet, Aïo
Romanian: Ai, Usturoi
Russian: Chesnok, Esnok, Luk Chesnok, Luk Posevnoi
Serbian: Beli Luk, Češnjak, Češan Luk, Češanj
Slovašcina: Česen, Luk-Česen
Slovencina: Cesnak Kuchynský
Spanish: Ajo, Ajo Común
Sri Lanka: Lashunaa (Sinhalese)
Swahili: Kitunguu Saumu
Swedish: Vitlök, Vitløk
Swiss: Ail
Tajik: Sirpiyoz, Sir, Sarimsok
Thai: Krathiam, Hom-Tiam
Tibetan: Gogpa, Sgog Gcig, Sgog pa, Sgog Skya, Sgog-Skyam
Tigrinya: Shegurti Tseda
Turkish: Sarımsak, Sarımsağı (Adi), Sarmesak, Sarmusak
Turkmen: Sarymsyk
Twi: Gyene Kankan
Ukrainian: Chasnyk, Chasnyk Horodni
Uzbek: Sarimsoq
Vietnamese: Cây Tỏi, Tỏi
Welsh: Craf, Craf Ewinog, Craf y Gerddi, Garlleg
Yiddish: Knobl

Origin/Distribution

Studies by Hong and Etoh (1996) and Etoh et al. (2001) proposed the Tian Shan mountains in Central Asia to be the primary centre of origin of garlic (*Allium sativum*) and the secondary centre in the Mediterranean and Caucasus zones (Etoh and Simon 2002). The Tian Shan mountain range straddles the border regions of Kazakhstan, Kyrgyzstan and the Xinjiang Uyghur Autonomous Region of western China. *A. sativum* has been postulated to be transported from Central Asia to the Mediterranean and other areas of cultivation (Maaß and Klaas 1995). *Allium longicuspis* Regel is believed to be the progenitor of domesticated garlic, and it occurs within the range of the species *A. sativum* (Maaß and Klaas 1995; Mathew 1996; Etoh and Simon 2002).

Garlic has been domesticated since antiquity and has been mentioned in ancient Egyptian, Babylonian, Greek, Indian and Chinese historical manuscripts. Garlic is also mentioned in the Bible and Qur'an. Today garlic is grown globally in both warm temperate and subtropical areas, and many cultivars have been developed to suit different climates. The main garlic producers based on 2012 production figures are China (20,000,000 tonnes), India (1,150,000 tonnes), Egypt (309,155 tonnes), Republic of Korea (339,113 tonnes), Russian Federation (239,312 tonnes), Bangladesh (233,609 tonnes), Ethiopia (225,548 tonnes), Myanmar (213,000 tonnes), United States (195,910 tonnes), Ukraine (171,400 tonnes), Spain (151,900 tonnes), Argentina (135,000 tonnes) and Brazil (107,009 tonnes) (FAO 2013).

Agroecology

In its native range, *Allium sativum* is found in the following habitats: rocky valleys, riverbeds, streambeds and gullies.

Garlic thrives in well-drained, rich and friable soils in the cooler climates from 9 to 28 °C, and in the tropics it is cultivated in the cooler higher elevations above 1,500 m. For bulb formation a 2-month duration of 10–15 °C is required.

Edible Plant Parts and Uses

Garlic bulbs are used as a spice or condiment in various dishes, raw or cooked. Minced garlic is used raw in salads. Raw garlic appears in quite a multitude of Mediterranean sauces. Notable examples are the Provençal specialty *aïoli*, a mayonnaise based on olive oil and enriched with raw garlic; the Greek *skordalia*, a paste made from cooked potatoes and raw garlic; the Turkish *çaçık*, a refreshing soup made from plain yogurt,

shredded cucumber, garlic and peppermint leaves; and the Greek *tsarsiki*, a thick garlic sauce served with barbecued lamb souvlaki. Elsewhere examples include the Chinese salad *suan ni huang-gua* of crunchy cucumber cubes with a dressing of vinegar, sesame oil and garlic, topped with coriander leaves; the Nepal Newari *kochila* of lean buffalo mince mixed with mustard oil and served with loads of raw garlic cloves; grated garlic is used in Vietnamese spring rolls and soups. Fresh garlic is crushed and left in water with added Sichuan pepper to prepare the Tibetan garlic water *gog-chu*. Raw garlic may be pickled in vinegar or oil usually olive. Fried and cooked garlic is commonly used in almost every cuisine of the world in stir-fries with meat, seafood or eggs and in soups, stews, noodles, pastas, curries, pizzas, sauces, mixed spices and pastes. Oils are often flavoured with garlic cloves.

The leaves, immature scapes and inflorescence stalks are eaten as vegetables. Chopped leaves are used in salads, and inflorescence stalks are cut into piece and are used in stir-fries with eggs, meat or other vegetables. The scapes are similarly used or prepared like asparagus and have a milder taste than the cloves. The sprouted seeds are added to salads. In some cuisine, the young bulbs are pickled for 3–6 weeks in a mixture of sugar, salt and spices. In eastern Europe the shoots are pickled and eaten as an appetiser.

Botany

Low, erect annual herb 30–60 cm high with a depressed globose to broadly ovoid solitary bulb up to 6 cm diameter made up of several cloves or bulbils covered with a common membranous, entire whitish to purplish tunic. The cloves comprised a series of functional leaves. Roots are adventitious. Real stem is much reduced to a basal disc at the base of the bulb. Pseudostem is formed by the sheathing bases of the leaves. Leaves broadly linear to linear-lanceolate, shorter than scape, to 2.5 cm wide, apex acuminate, glabrous with smooth margin. The scape is 50–100 cm, erect, terete. Inflorescence is a hemispherical umbel, 2.5–5 cm diameter, comprising numerous bulbils and a few flowers and covered with a membranous spathe that split to one side on opening. Pedicels slender up to 4 cm long. Bracteoles ovate, large, membranous, apex acute. Flowers are sub-campanulate, tepals ovate-lanceolate in two whorls, and up to 4 mm long, greenish purple, stamens in two whorls and pistil globose, tricarpellate, style not exserted. Fruit abortive and without seeds (Plates 1, 2, 3, 4, 5, 6, and 7).

Nutritive/Medicinal Properties

The nutritional value per 100 g of peeled garlic cloves (i.e. 79 % of the dry bulb weight) was reported as: water 64.3 g, energy 411 kJ (98 kcal), protein 7.9 g, fat 0.6 g, carbohydrate

Plate 1 Harvested white garlics

Plate 2 Purplish garlic cloves

Plate 3 Garlic bulb

Plate 6 Garlic flower inflorescence and stalk (edible)

Plate 4 Imbricate garlic bulb

Plate 7 Garlic inflorescence bulbils

Plate 5 Harvested garlic flower stalks (edible)

16.3 g, dietary fibre 4.1 g, Ca 19 mg, P 170 mg, Fe 1.9 mg, carotene trace, thiamine 0.13 mg, riboflavin 0.03 mg, folate 5 µg and ascorbic acid 17 mg (Holland et al. 1991). The nutritional composition of garlic bulb per 100 g edible portion was reported as: water 58.58 g; energy 623 kJ (149 kcal); protein 6.36 g; fat 0.5 g; carbohydrate 33.06 g; total dietary fibre 2.1 g; total sugars 1.00 g; ash 1.50 g; Ca 181 mg; Mg 25 mg; P 153 mg; K 401 mg; Na 17 mg; Fe 1.70 mg; Zn 1.16 mg; Cu 0.299 mg; Mn 0.1672 mg; Se 14.2 µg; vitamin C (total ascorbic acid) 31.2 mg; thiamine 0.200 mg; riboflavin 0.110 mg; niacin 0.700 mg; total folate 3 µg; total choline 32 mg; pantothenic acid 0.596 mg; vitamin A 9 IU; β-carotene 5 µg; lutein + zeaxanthin 16 µg; vitamin E (α-tocopherol) 0.08 mg; vitamin K (phylloquinone) 1.7 µg;

total saturated fatty acids 0.089 g, 10:0 0.002 g; 16:0 (palmitic acid) 0.087 g; total monounsaturated fatty acids 0.011 g; 18:1 undifferentiated (oleic acid) 0.011 g; total polyunsaturated fatty acids 0.249 g, 18:2 undifferentiated (linoleic acid) 0.229 g, 18:3 undifferentiated (linolenic acid) 0.020 g; and amino acids, tryptophan 0.066 g, threonine 0.157 g, isoleucine 0.217 g, leucine 0.308 g, lysine 0.273 g, methionine 0.076 g cystine 0.065 g, phenylalanine 0.183 g, tyrosine 0.081 g, valine 0.291 g, arginine 0.634 g, histidine 0.113 g, alanine 0.132 g, aspartic acid 0.489 g, glutamic acid 0.805 g, glycine 0.200 g, proline 0.100 g and serine 0.190 g (USDA, ARS 2014).

Selenium level was found to be 0.015 µg/g for garlic (Izgi et al. 2006). An essential fatty acid, ethyl linoleate, was isolated from the garlic cloves (Park et al. 2014). Garlic had been reported to contain 0.41 % phosphorus to constitute more than 10 % of its ash (Anantakrishnan and Venkataraman 1940). Garlic was also found to contain 30.5 % of total phosphorus as phytin which comprised the major fraction of barium-precipitable acid-soluble phosphorus. This fraction largely composed of the resistant hexose monophosphate 65 %, and labile phosphorus compounds 35 %, whose nature was not identified. Crude protein, dimethyl sulfite and essential oil contents were determined as 17.2 %, 1,779 µcg/kg and 0.14 %, respectively, in garlic bulb (Hacıseferoğulları et al. 2005). In addition, K (21,378.84 mg/kg), P (6,009.37 mg/kg), Mg (1,056.15 mg/kg), Na (532.78 ppm) and Ca (363.61 ppm) were reported as the major minerals in garlic bulbs. Six water-soluble vitamins including thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6) and cobalamin (B12) were separated from different garlic extracts (Abd Al-Timimi et al. 2013). The highest concentration belongs to vitamin B3 (niacin) in all types of aqueous garlic extracts, Iraqi, Iranian, Lebanese, French and Chinese aqueous garlic extracts, but the highest level concentration was in Iraqi garlic extract (15.58) ppm.

Lipids

Total lipid ranged from 310 to 342 mg/100 g in fresh garlic (Yang and Shin 1982). These lipids were shown to consist of 36.4–43.5 % neutral lipids, 20.3–24.3 % glycolipids and 36.2–39.3 % phospholipids. Among the neutral lipids, triglycerides were predominant (80.5–83.6 %) and esterified steryl glycosides and steryl glycosides were major sugar-containing lipids. Of the phospholipids, phosphatidyl cholines and serines and phosphatidyl ethanolamines were the major components, comprising over 85 % of this class. The major fatty acids in the total and lipids classes were linoleic, palmitic, oleic and linolenic aid. Eighty percent of the total lipids of *Allium cepa*, *Allium sativum* and *Allium porrum* were found to consist of four fatty acids: linoleic (46–53 %), palmitic (20–23 %), oleic (4–13 %) and α-linolenic acid (3–7 %) (Tsiaganis et al. 2006). In garlic, 70 fatty acids are determined, 14 of that above 0.4 % and only 4 above 2.5 %. Phospholipids consisted of a limited number of specific fatty acids, while neutral lipids contained a wide range including some unusual fatty acids.

Garlic lipids comprised 62.6 % neutral lipids (NL), 14.0 % glycolipids and 23.4 % phospholipids (PL) (Kamanna and Chandrasekhara 1980). Garlic lipids contained a considerably high percentage of polar lipids. The fatty acid composition of the total lipids (TL) and component fractions showed that palmitic, oleic, linoleic and linolenic acids constituted the major fatty acids; capric, lauric, myristic and stearic acids amounted to about 6 % in all the lipid fractions. The unsaturated fatty acids together amounted to 72–80 %, and among these, linoleate was predominant in total lipids as well as in the NL and PL fractions. The glycolipid fraction was richer in linolenate (37.5 %) compared to 4–9.5 % in TL, NL and PL. Neutral lipids of garlic contained considerable quantities of monoglycerides (18.5 %), diglycerides (14.2 %), sterols (16.3 %) and triglycerides (41.5 %), respectively (Kamanna and Chandrasekhara 2006). The phospholipid fraction was rich in phosphatidyl choline (23.5 %),

phosphatidyl ethanolamine (17.9 %), lysophosphatidyl choline (11.8 %) and lysophosphatidyl ethanolamine (8.2 %). Digalactosyl diglyceride (10.1 %), sterol glycoside (15.6 %), cerebrosides (8.1 %), acylsterol glycoside (38.6 %) and monogalactosyl diglyceride (22.5 %) were the major components of the glycolipids of garlic. Lauric, myristic, palmitic and linoleic acids constituted the major fatty acids of monoglycerides, diglycerides and free fatty acid fractions, whereas palmitic, linoleic and linolenic acids were the major fatty acids of triglycerides. Palmitic and linoleic acids were the major fatty acids of garlic phospholipids. Except the acylsterol glycoside fraction glycolipids were rich in lauric, palmitic, linoleic and linolenic acids; palmitic acid was the only major fatty acid of acylsterol glycosides.

Fructans/Polysaccharides/Peptides/Protein

Hot water extraction of defatted garlic bulbs yielded a mixture of polysaccharides containing a D-galactan, a D-galacturonan, an L-arabinan, a D-glucan and a D-fructan (Das and Das 1977). A trace of L-rhamnose was also detected in the polysaccharide hydrolysate. The fructan component contained fructose (94.4 %) and glucose (4.3 %) (Das and Das 1978). Methanolysis and hydrolysis of the permethylated fructan gave (*a*) 1,3,4,6-tetra-*O*-methyl-D-fructose, (*b*) 2,3,4,6-tetra-*O*-methyl-D-glucose, (*c*) 2,4,6-tri-O-methyl-D-glucose and (*d*) 3.4,6-tri-*O*-methyl-d-fructose. On periodate oxidation, the fructan reduced one molar equivalent of the oxidant per hexosyl residue and liberated one molar equivalent of formic acid per 51 hexosyl residues. In *Allium cepa* (cv. Creamgold), *A. cepa* (cv. Bunching Onion), *A. porrum* (leek) and *A. sativum* (garlic), fructans were the only nonstructural carbohydrates detected apart from glucose, fructose and sucrose (Darbyshire and Henry 1981). *A. sativum* was different from the rest in that larger polymers of fructans were present, reaching a (degree of polymerisation) DP of 50. The trisaccharides, 1^F-fructosylsucrose and 6^G-fructosylsucrose, were found in all species. *A. cepa* and *A. sativum* contained similar fructan: fructan fructosyltransferases. Enzymes from both plants transferred fructosyl residues from trisaccharide to form tetrasaccharide and sucrose as the major products. Xyloglucans were isolated from the cell walls of bulbs of onion (*Allium cepa*), garlic (*Allium sativum*) and their hybrid (Ohsumi and Hayashi 1994). The polysaccharides yielded single peaks upon gel filtration with average molecular weights of 65,000 for onion, 55,000 for garlic and 82,000 for the hybrid. The polysaccharides were constructed of four kinds of a repeating oligosaccharide unit, namely, a decasaccharide (glucose/xylose/galactose/fucose, 4:3:2:1), a nonasaccharide (glucose/xylose/galactose/fucose, 4:3:1:1), an octasaccharide (glucose/xylose/galactose, 4:3:1) and a heptasaccharide (glucose/xylose, 4:3). The xyloglucan from the hybrid contained highly fucosylated units that resembled those from onion rather than from garlic. Garlic cloves contained a high concentration of oligo- and polyfructosaccharides, ranging from 125 to 235 mg/g, on a wet weight basis (Losso and Nakai 1997). Fructose–glucose ratio in the fructooligo/fructopolysaccharides was about 15:1. Molecular masses of fructans ranged from less than 1,000 Da to around 4,500 Da, corresponding to DP as high as 38. A high molecular weight fructan belonging to the neo-ketose family was isolated from garlic (Baumgartner et al. 2000). Garlic fructan, an insulin-type fructan, possessed a (2→1)-linked β-D-Fruf backbone with (2→6)-linked β-D-Fruf side chains with a degree of polymerisation of about 58. Zhang et al. (2012b) isolated a low molecular weight fructooligosaccharide (LMWF) from garlic. LMWF was a neo-ketose with a molecular weight of 1,770 Da and had a (2,1)-linked β-D-Fruf backbone with (2,6)-linked β-D-Fruf side chains, and it was mainly composed of fructose. Both high molecular weight (>3.5 kDa; HF) and low molecular weight (<3 kDa; LF) fructans were isolated from aged garlic extract (Chandrashekar et al. 2011). Both have (2→1) β-D-fructofuranosyl bonds linked to a terminal glucose at the non-reducing end and β-D-fructofuranosyl branching on its backbone.

The composition of fructooligosaccharides (FOS), together with glucose, fructose and sucrose, had been determined in commercial dehydrated samples of onion and garlic (Cardelle-Cobas et al. 2009). No qualitative differences were detected among the FOS identified in both onion and garlic. Results showed a lower FOS content in garlic than in onion in all samples analysed. In garlic samples, FOS with a degree of polymerisation from 3 to 7 were identified and quantified for the first time. Considering FOS fraction, trisaccharides: 1-kestose (1_F-β-D-fructofuranosylsucrose), neokestose (6^G-β-D-fructofuranosylsucrose); tetrasaccharides: nystose[1_F(1-β-D-fructofuranosyl)$_2$sucrose], 6^G(1-β-D-fructofuranosyl)$_2$ sucrose and 1_F(1-β-D-fructofuranosyl)-6^G(1-β-D-fructofuranosyl) sucrose; pentasaccharides:1_F(1-β-D-fructofuranosyl)$_3$ sucrose, 6^G(1-β-D-fructofuranosyl)$_3$ sucrose, 1_F(1-β-D-fructofuranosyl)$_2$-6^G (1-β-D-fructofuranosyl) sucrose and 1_F(1-β-D-fructofuranosyl)-6^G (1-β-D-fructofuranosyl) $_2$ sucrose; hexasaccharides: 1_F(1-β-D-fructofuranosyl)$_4$sucrose, 6^G(1-β-D-fructofuranosyl)$_4$ sucrose, 1_F(1-β-D-fructofuranosyl)$_3$ -6^G(1-β-D-fructofuranosyl) sucrose, 1_F(1-β-D-fructofuranosyl)-6^G(1-β-D-fructofuranosyl)$_3$ sucrose and 1_F(1-β-D-fructofuranosyl)$_2$-6^G(1-β-D-fructofuranosyl)$_2$ sucrose; and heptasaccharides: 1_F(1-β-D-fructofuranosyl)$_5$ sucrose were found in onion and in garlic samples.

Alliin lyase was purified up to sevenfold from garlic bulb homogenates (Mazelis and Crews 1968). Alliin lyase purified from garlic was found to have a molecular mass of 108,000 and to consist of two equal subunits (Jansen et al. 1989). The enzyme was found to be thermolabile. The activities of γ-glutamyl transpeptidase/γ-glutamyl peptidase enzymes were determined in sprouted garlic bulbs (Ceci et al. 1992). A novel amino acid glycoside (–)-*N*-(1′-deoxy-1′-β-d-fructopyranosyl)-*S*-allyl-L-cysteine sulfoxide was isolated from a hydrophilic extract of garlic leaves (Mütsch-Eckner et al. 1993). Fractions of garlic aqueous extract with high angiotensin I-converting enzyme (ACE) inhibitory activity yielded seven dipeptides with ACE inhibitory properties (Suetsuna 1998). These dipeptides were identified as Ser–Tyr, Gly–Tyr, Phe–Tyr, Asn–Tyr, Ser–Phe, Gly–Phe and Asn–Phe. (*R*)-3-(allylthio)-2-((*R*)-3-(allylthio)-2-aminopropanamido)propanoic acid, a dipeptide, was isolated from garlic bulb, together with four known amino acids (Zhou et al. 2014a). Garlic polysaccharide was modified by the HNO3–Na2SeO3 method to obtain nine selenising garlic polysaccharides, sGPS1–sGPS9 (Qiu et al. 2014).

Two novel lectins were isolated from garlic roots and leaves (Smeets et al. 1997b). The leaf lectin ASAL was a dimer of two identical subunits of 12 kDa, which closely resembled the leaf lectins from onion, leek and shallot with respect to its molecular structure and agglutination activity. In contrast, the root lectin ASARI was a dimer of subunits of 15 kDa, strongly different from the leaf lectin with respect to its agglutination activity. cDNA cloning of the leaf and root lectins revealed that the deduced amino acid sequences of ASAL and ASARI were virtually identical. Garlic bulb contained both heterodimeric mannose-binding lectins ASAI (*Allium sativum* agglutinin I) and homodimeric lectin ASAII (*Allium sativum* agglutinin II) (Smeets et al. 1997a). It was found that only the heterodimeric lectin ASAI was capable of binding to the glycan chains of the alliinase molecule in garlic bulb. It appeared that only a subpopulation of the alliinase molecules was involved in the formation of lectin–alliinase complexes and that the complexed alliinase contained more glycan chains than the free enzyme. Dam et al. (1998) also purified two mannose-binding lectins, *Allium sativum* agglutinin (ASA) I (25 kDa) and ASAIII (48 kDa), from garlic bulbs. Both ASAI and ASAIII comprised of 12.5- and 11.5-kDa subunits. In addition, a complex (136 kDa) comprising a polypeptide chain of 54 kDa and the subunits of ASAI and ASAIII eluted earlier than these lectins on gel filtration. The 54-kDa subunit was confirmed to be alliinase, known to form a complex with garlic lectins. Constituent subunits of ASAI and ASAIII exhibited the same sequence at their amino termini. The potencies of the ligands for ASAs increased in the following order: mannobiose (Manalpha1-3Man) <mannotriose

(Manalpha1-6Manalpha1-3Man) approximately mannopentaose << Man9-oligosaccharide. Interaction with glycoproteins suggested that these lectins recognised internal mannose as well as bind to the core pentasaccharide of N-linked glycans even when they were sialylated. Glycosylated dimeric alliinase was purified to homogeneity from garlic (Kuettner et al. 2002).

Agglutinins of 110 and 25 kDa (ASA110 and ASA25) were isolated from garlic (Gupta and Sandhu 1997). ASA25 was a dimeric protein comprising of subunits of 12.5 and 13.0 kDa and ASA110 a glycoprotein of two identical subunits of 47 kDa. ASA110 had a high content of aspartic acid, glycine, leucine and serine but low content of cysteine and methionine. It contained 14 residues of neutral sugars in addition to 43 residues of hexosamines per mole of lectin and requiring metal ions for its functional conformation. Serological cross-reactions with other species showed some common epitopes of ASA110 and ASA25 present in *A. porrum*, *A. ascalonicum*, *Narcissus* alba, PHA and Con A but not in *A. cepa*. ASA110 with CHO cells indicated it to be weakly cytotoxic with LD_{50} of 160 μg/mL. Results from in-vitro analysis indicated a higher homology of garlic LECASAI lectin with those of insecticidal lectins and the presence of mannose-binding region in LECASAI (Gogia et al. 2014).

The garlic plant alliinase, which catalyses the synthesis of allicin, was purified to homogeneity from garlic bulbs (Rabinkov et al. 1994). The enzyme was found to be a glycoprotein containing 6 % carbohydrate and a dimer of two subunits of MW 51.5 kDa each. 13-hydroperoxide-specific divinyl ether synthase activity was found in the microsomal fraction of garlic bulbs (Grechkin and Hamberg 1996). The enzyme was found to utilise 13(*S*)-HPOD as its preferential substrate and possessed stereoselectivity, utilising preferentially the (*S*)-enantiomer. A protein-designated alliumin, with a molecular mass of 13 kDa and an N-terminal sequence similar to a partial sequence of glucanase, was isolated from garlic cloves (Xia and Ng 2005). Phospholipase D bulbs (PLD_{GB}) were identified and partially characterised from garlic (Khatoon et al. 2008). PLD_{GB} exhibited both hydrolytic and transphosphatidylation activities, both of which appeared to be higher than those of PLD from cabbage leaves. Garlic extract and its protein fraction significantly and dose dependently augmented oxidative burst of T-lymphocyte (Lau et al. 1991). The protein fraction also enhanced the T-lymphocyte blastogenesis. The data suggested that garlic compounds may serve as biological response modifiers by augmenting macrophage and T-lymphocyte functions. Two major proteins (12–14 kDa) were detected in aged garlic extract; the purified protein components QA-1, QA-2 and QA-3 displayed immunomodulatory and mannose-binding activity (Chandrashekar and Venkatesh 2009). Three protein components of molecular weight ~13 kD (QR-1, QR-2 and QR-3 in the ratio 7:28:1) were separated from raw garlic extract (Clement et al. 2010). Studies indicated that characteristics of major proteins QR-2 and QR-1 present in a ratio of 4:1 in raw garlic were markedly similar to the abundant *Allium sativum* agglutinins (ASA) I and II, respectively (Clement et al. 2010; Clement and Venkatesh 2010). The two proteins actin and myosin were found to be co-localised and closely linked to each other in plasmodesmata- and ectodesmata-like structure in ageing parenchymatous cells of *Allium sativum* (Dong et al. 2011). A cellulase gene from garlic was cloned and characterised in gene and protein levels (Kim et al. 2010). The DNA sequence of the garlic cellulase gene showed 81 % identity with the sequence of the endo-β-1,4-glucanase of *Pisum sativum*. A superoxide dismutase was purified and characterised from garlic (Liu et al. 2011) The native enzyme was homodimeric and had a native molecular mass of 28 kDa. A 47-kDa protein was extracted from aged garlic (Ahmadabad et al. 2012).

Phenolic Compounds/Flavonoids/Anthocyanins

Cyanidin 3-*O*-glucoside was the main anthocyanin in the external layer of garlic clove (Du and Francis 1975). Acidified methanolic extract of

inner scale leaves of garlic contained mostly anthocyanins with aliphatic acylation. These are the rare 3″,6″-dimalonylglucoside (13 %) and 3″-malonylglucoside (3 %) of cyanidin, in addition to cyanidin 3-(6″-malonylglucoside) (71 %) and cyanidin 3-glucoside (12 %) (Fossen and Andersen 1997).

Low-temperature (5 °C) conditioning of garlic 'seed' cloves accelerated the development of the crop cycle, decreased plant growth and increased the synthesis of phenolic compounds and anthocyanins in the outer scale leaves of the bulbs at harvest time, leading to 3-fold content increase compared with those conditioned at room temperature (Dufoo-Hurtado et al. 2013). Cold conditioning of 'seed' cloves also altered the anthocyanin profile during bulb development and at harvest. On both sampling dates (122 and 158 days after sowing(DAS)), total phenolic content was higher in cloves conditioned at 5 °C (3.25 and 1.87 mg GAE/g of freeze-dried cataphylls, respectively) than in cloves sampled at (122 and 200 DAS) stored at room temperature (2.61 and 0.61 mg GAE/g of freeze-dried cataphylls, respectively). Similarly total anthocyanin content was higher in cloves conditioned at 5 °C (1.156 and 0.380 mg C3G/g of freeze-dried cataphylls, respectively) than in cloves stored at room temperature (0.89 and 0.103 mg C3G/g of freeze-dried cataphylls, respectively). Five anthocyanins were identified in the outer scale leaves of garlic bulbs cv Coreano: cyanidin 3-*O*- glucoside (C3G), cyanidin 3-*O*-(3″-malonyl) glucoside, cyanidin 3-*O*-(3″-acetoyl) glucoside, cyanidin 3-*O*-(6″-malonyl) glucoside and cyanidin 3-*O*-(6″-malonyl acetoyl) glucoside. Putative genes involved in the biosynthesis of anthocyanins and phenolic compounds in garlic sprouts were identified as phenylalanine ammonia lyase, cinnamate 4-hydrolyase, 4-coumarate-CoA ligase, UDP-glucose–flavonoid 3-*O*-glycosyltransferase and sucrose–sucrose 1-fructosyltransferase. The high phenolics and anthocyanin contents in bulbs of plants generated from 'seed' cloves conditioned at 5 °C for 5 weeks were preceded by the overexpression of some putative genes of the phenolic metabolism (6-fold for phenylalanine ammonia lyase) and anthocyanin synthesis (1-fold for UDP-glucose–flavonoid 3-*O*-glycosyltransferase) compared with those conditioned at room temperature.

The bulbs of garlic contained only few milligrams of glycosides of kaempferol and quercetin per kg fresh weight (Starke and Herrmann 1976). Four flavonols quercetin 3-O-β-d-glucopyranoside (isoquercitrin), quercetin 3-*O*-β-d-xylopyranoside (reynoutrin), kaempferol 3-*O*-β-D-glucopyranoside (astragalin) and isorhamnetin 3-*O*-β-D-glucopyranoside and their aglycones quercetin, kaempferol and isorhamnetin were isolated from garlic leaf and shoot (Kim et al. 2005). Garlic contained the flavonols kaempferol 0.3 mg, myricetin 1.6 mg and quercetin 1.7 mg (Kevers et al. 2007).

The total phenolic content in garlic varied from 3.4 mg to 10.8 mg gallic acid equivalents (GAE)/g with a mean value of 6.5 mg GAE/g dm (Beato et al. 2011). The myricetin, quercetin, kaempferol and apigenin flavonoids were not detected in any of the samples. Caffeic acid and ferulic acid were the major phenolic acids found with mean values of 2.9 mg/kg dm and 2.6 mg/kg dm, respectively. The mean contents of vanillic, p-hydroxybenzoic and *p*-coumaric acids were comparable (0.4–0.8 mg/kg of dm), and the level of sinapic acid was negligible (<0.1 mg/kg of dm). There was a significant effect of location but an insignificant effect of genotype on contents of caffeic, vanillic, *p*-hydroxybenzoic and *p*-coumaric acids. However, genotype but not location affected the contents of total phenolics and ferulic acid. On average, the white garlic cultivars and Chinese garlic cultivars contained higher contents of total phenolics and ferulic acid than the purple garlic cultivars. However, the differences in the total phenolic content between the purple and white garlic cultivars were not significant. The following major phenolic compounds were identified and quantified (mean values) in garlic: flavonol quercetin 13.9 mg/kg, phenolic acids caffeic acid 7.2 mg/kg and ferulic acid 3.5 mg/kg and flavone apigenin 1.9 mg/kg DW (Alarcón-Flores et al. 2014).

Black garlic was produced in a ripening chamber by using a programmed stepwise heating schedule, and the total phenolic content (TPC)

and total flavonoid content (TFC) of the garlic subjected to different thermal processing steps were higher than those of fresh garlic (Kim et al. 2013). Hydroxycinnamic acid derivatives were found to be the major phenolic acids of garlic at different processing steps. Among the four major flavonoid subgroups in garlic, flavonols were found at the highest concentrations followed by flavanones and flavones, except in the fresh garlic sample.

Sulfur Compounds

Cavallito et al. (1944, 1945; Stoll and Seebeck 1949, 1951) showed that garlic contained S-allylcysteine sulfoxide (alliin) and an enzyme alliinase which acted on alliin, generating diallyl thiosulfinate (allicin) CH_2=CH–CH_2S(=O). SCH_2–CH=CH_2. Addition of *S*-allyl-L-cysteine markedly increased the level of alliin in both shoot-forming and root-forming callus tissues of *A. sativum* (Ohsumi et al. 1993). The content of alliin and other *S*-alk(en)ylcysteine sulfoxides was determined in nine different samples of garlic (*Allium sativum* L.) originating from the Czech Republic, France and China (Kubec et al. 1999). The total content of *S*-alk(en)ylcysteine sulfoxide pool ranged between 0.53 and 1.3 % fresh weight, with *S*-allylcysteine sulfoxide (alliin) being predominant. A novel *S*-alkylcysteine derivative, *S*-ethylcysteine sulfoxide (ethiin), not previously reported to occur in *Allium* species, was found in some of the garlic samples.

Allithiamine, a newly found derivative of vitamin B1 (thiamine), was first identified in heated garlic in 1950 (Fujiwara et al. 1954). It was later confirmed that similar compounds could be formed using other *Allium* vegetables from compounds similar to allicin, and a study in rabbits appeared to show that allithiamines were formed in situ in the intestine in the presence of garlic and thiamine (Fujiwara 1976). Methyl, ethyl and propyl derivatives of alliin, allicin and allithiamine were identified in garlic and other *Allium* (Fujiwara et al. 1958). (–) *S*-Allyl-L-cysteine (Suzuki et al. 1962), (–) *S*-propenyl-L-cysteine (Sugii et al. 1963), γ-L-glutamyl-*S*-allylmercapto-l-cysteine and *S*-allylmercapto-L-cysteine (Sugii et al. 1964) were isolated from garlic bulb. A thioglycoside scordinin A_1 was isolated from boiled garlic, and its structure was elucidated as R-CH: CH-CH_2-S-$C_6H_8O_6 \cdot 1/2$Ca, in which R was a peptide containing a new amino acid and the carbohydrate part was calcium fructuronate (Kominato 1969a). On acid hydrolysis of scordinin A_1, fructuronic acid was detected, and by garlic enzyme allyl mercaptan was confirmed (Kominato 1969b). On hydrolysis with barium hydroxide, one kind of peptide, scormin, was isolated. From the results, the author postulated that allyl thiofructuronic acid combined with scormin to form scordinin A_1. Diallyl thiosulfinate was found to be a major constituent of solvent extracted garlic (Brodnitz et al. 1971). On dehydration, it formed two isomeric disulfides. At room temperature it undergoes a rearrangement. After 24 hours, sulfur dioxide, diallyl mono-, di- and trisulfides were the major products.

Two γ-glutamyl-*S*-alkylcysteines, namely, γ-glutamyl-*S*-*trans*-1-propenyl cysteine and γ-glutamyl-*S*-allylcysteine, were found to be in homogenates of fresh picked garlic cloves; both were found to decrease markedly when fresh picked garlic was stored at 4 °C (Lawson et al. 1991a). Six *S*-alk(en)yl-L-cysteine sulfoxides and γ-L-glutamyl-*S*-alk(en)yl-L-cysteines including (+)-*S*-allyl-L-cysteine sulfoxide, γ-L-glutamyl-*S*-allyl-l-cysteine and γ-L-glutamyl-*S*-(*trans*-1-propenyl)-L-cysteine were found in garlic (Mütsch-Eckner et al. 1992b). Four γ-glutamyl peptides were isolated from a hydrophilic extract of garlic bulbs: γ-L-Glutamyl-*S*-(*trans*-1-propenyl)-L-cysteine; γ-L-glutamyl-*S*-allyl-L-cysteine;γ-L-glutamyl-*S*-(*trans*-1-propenyl)-L-cysteine; and γ-L-glutamyl-*S*-allylthio-L-cysteine (Mütsch-Eckner et al. 1992a). Among glutamyl peptides, γ-glutamyl-*S*-allyl-L-cysteine (GSAC) and γ-glutamyl-*S*-*trans*-1-propenyl-L-cysteine (GSPC), γ-glutamyl-*S*-*trans*-1-propenyl-L-cysteine (GSPC) was predominant, followed by γ-glutamyl phenylalanine (γGPA) in garlic cloves (Yoo et al. 2010). The contents of GSAC, GSPC and γGPA were a range of 13.04–23.51, 17.40–27.00 and 5.51–9.62 mg/g garlic (dry weight), respectively. γ-Glutamyl-*S*-methyl-L-cysteine (GSMC) was present in a small amount

(0.85–1.39 mg/g garlic). The content of alliin, the most abundant sulfur compound in whole garlic, was 25.65–30.03 mg/g garlic. The amount of allicin, a major bioactive compound of garlic and garlic preparations, was 3.25–4.60 mg/g garlic. The contents of *S*-allylcysteine (SAC) and *S-trans*-1-propenyl-L-cysteine sulfoxide (isoalliin) were 0.36–0.60 and 0.14–0.54 mg/g garlic, respectively. *S-trans*-1-propenyl-L-cysteine (SPC) was found only in trace amounts in raw garlic bulbs. There was a significant effect of the location, cultivar and garlic ecotype on the contents of the following organosulfur compounds studied, three γ-glutamyl peptides, namely, γ-L-glutamyl-*S*-(2-propenyl)-L-cysteine (GSAC), γ-L-glutamyl-*S*-(*trans*-1-propenyl)-L-cysteine (GSPC) and γ-L-glutamyl-*S*-methyl-L-cysteine (GSMC) and four cysteine sulfoxides (alliin, isoalliin, methiin and cycloalliin) (Montaño et al. 2011). Purple-type cultivars showed on average the highest contents of GSMC, GSAC, alliin and methiin but the lowest isoalliin content. The impact of genotype was relatively high for GSAC, whereas this factor hardly contributed to the total variability in alliin and isoalliin content. Planting date had a significant effect on the content of alliin and isoalliin.

According to Block (1992) most of the non-protein sulfur in *Allium* could be found in the form of four principal ACSOs: methyl (MeCSO), 2-propenyl (2-PeCSO), 1-propenyl (1-PeCSO) and propenyl (PeCSO). 1-PeCSO was found in the highest concentration in onions, and 2-PeCSO was found in the highest concentrations in garlic with only trace amounts in onions. Among three common *Allium* crops, the total ACSO concentration was generally highest in garlic, intermediate in onion and lowest in leek (Block 1992; Coley-Smith 1986). Of eight *Allium* species, garlic and giant garlic contained the greatest amounts of total *S*-alk(en)yl-L-cysteine sulfoxides (ACSO) (5.0–11.7 mg/g); Chinese chive, dehydrator onion, leek and shallot had moderate amounts (2.0–5.0 mg/g), and Japanese bunching onion, onion (TG 1015Y) and chive leaves contained the least amounts of total CSO (<2 mg/g) (Yoo and Pike 1998). AlCSO (*S*-allyl-L-cystine sulfoxide, alliin) was the major precursor in garlic and giant garlic (3.2–9.8 mg/g) and was also contained in chive and Chinese chive. PeCSO (*S*-propenyl-L-cysteine sulfoxide) was the main flavour precursor in onion, green onion, leek and shallot (0.3–2.2 mg/g), but also found in chive, Chinese chive, garlic and giant garlic. MeCSO (*S*-methyl-l-cysteine sulfoxide) was a major precursor in chive and Chinese chive (0.68–1.85 mg/g fresh wt.) and found in all eight species examined with less amounts. *S*-propyl CSO, however, was not found in any of these species. Allison et al. (2006a) reported aged garlic extract to be a complex mixture containing allin, cycloalliin, *S*-allyl-l-cysteine, *S*-methyl-L-cysteine, *S*-ethylcysteine, *S*-1-propenyl-L-cysteine, *S*-allylmercapto-L-cysteine, fructosyl-arginine, β-chlorogenin, L-arginine, L-cysteine and L-methionine.

Unsaturated acyclic sulfur-containing components may consist up to more than 70 % of the garlic oil (Kimbaris et al. 2006) Infrared spectra and relative retention volumes were used to confirm the production of asymmetric disulfides, methyl-allyl, methyl-*n*-propyl and allyl-*n* propyl compounds by *Allium sativum* (Jacobsen et al. 1964). Two new sulfur-containing amino acids γ-glutamyl-*S*-allylmercapto-L-cysteine and *S*-allylmercapto-L-cysteine were isolated from garlic bulbs (Sugii et al. 1964). A novel amino acid glycoside (–)-*N*-(1′-deoxy-1′-β-d-fructopyranosyl)-*S*-allyl-L-cysteine sulfoxide, together with three known compounds: (+)-S-allyl-L-cysteine sulfoxide, (+)-*S*-methyl-L-cysteine sulfoxide and (+)-*S*-(*trans*-1-propenyl)-L-cysteine sulfoxide, were isolated from a hydrophilic extract of garlic leaves (Mütsch-Eckner et al. 1993).

Potent antiplatelet compounds were isolated from garlic bulbs: diallyl trisulfide, 2-vinyl-1,3-dithiin and allyl 1,5-hexadienyltrisulfide (Apitz-Castro et al. 1983). Garlic extracts contained a compound termed ajoene, which was found to be a potent inhibitor of platelet aggregation (Block et al. 1984, 1986). The structure of ajoene was determined to be (*E* and *Z*)-4, 5, 9-trithiadodeca-1,6,11-triene 9-oxide. Ajoene was proposed to be formed by *S*-thioallylation of allicin, followed by Cope-type elimination and readdition of 2-propenesulfenic acid. Ajoene was reported to be produced most efficiently from pure allicin and possessed the advantage of a greater chemical

stability than allicin (Hassan 2004). Other ajoene-type organosulfur compounds *Z*-4,5,9-trithiadeca-1,6-diene-9-oxide (*Z*-10-devinylajoene; *Z*-10-DA) (Yoshida et al. 1998) and *E*-4,5,9-trithiadeca-1,7-diene-9-oxide, (iso-*E*-10-devinylajoene, iso-*E*-10-DA) were isolated from oil-macerated garlic extract (Yoshida et al. 1999a). The latter compound was different from *E*-4,5,9-trithiadeca-1,6-diene-9-oxide (*E*-10-devinylajoene, *E*-10-DA) only in the position of a double bond.

Three thiosulfinates were isolated from oil-macerated garlic extract, and their structures were identified as 2-propene-1-sulfinothioic acid S-(*Z*,*E*)-1-propenyl ester [AllS(O)SPn-(*Z*,*E*)], 2-propenesulfinothioic acid *S*-methyl ester [AllS(O)SMe] and methanesulfinothioic acid *S*-(*Z*,*E*)-1-propenyl ester [MeS(O)SPn-(*Z*,*E*)] (Yoshida et al. 1999b). A novel antifungal protein, designated allivin, with molecular weight of 13 kDa was isolated from garlic bulbs (Wang and Ng 2001). Three known compounds, *bis*-2-propenyl trisulfide, *bis*-2-propenyl tetrasulfide and *bis*-2-propenyl pentasulfide; two novel compounds, *bis*-2-propenyl thiosulfonate and *trans*-sulfuric acid allyl ester 3-allylsulfanyl-allyl ester (Hu et al. 2002); and *trans*-sulfurous acid allyl ester 3-allylsulfanyl-allyl-ester; 2-propene-1-sulfinothioic acid-S-methyl ester and 2-propene-1-sulfinothioic acid-*S*-(*E*)-1-propenyl ester were isolated from an aqueous ethanol garlic extract (Yang et al. 2003).

Sulfur metabolism of onions, garlic and chives differed in some but not all respects from that in other plants (Granroth 1970). The cysteine formed was not stored but reacted further to give various S-substituted derivatives of which *trans*-(+)-*S*-(propen-l-yl)-L-cysteine sulfoxide (CSO) was the most efficiently accumulated, and this compound appeared to be the most important precursor of the flavour substances in onion, garlic and chive. 1-Propenyl-L-cysteine sulfoxide (PeCSO) was the main flavour precursor in onion, green onion, leek and shallot (0.3–2.2 mg/g), but also found in chive, Chinese chive, garlic and giant garlic (Yoo and Pike 1998). *trans*-(+)-*S*-(propen-l-yl)-L-cysteine sulfoxide (CSO) was also found to be an important precursor of the flavour substances in onion, garlic and chive. *S*-methylcysteine sulfoxide (MeCSO) was a major precursor in chive and Chinese chive (0.68–1.85 mg/g fresh wt.) and found in garlic, onion and leek in lesser amounts. Four nonvolatile, odourless S-alk(en)yl cysteine sulfoxides (CSOs) were reported as the precursors of the flavour and odours of the *Allium* (Jones et al. 2004). These were *S*-methylcysteine sulfoxide (MeCSO, methiin; present in garlic, onion and other *Allium*), *S*-allylcysteine sulfoxide (ACSO, alliin; characteristic of garlic), *S*-*trans*-prop-1-enyl cysteine sulfoxide (PeCSO, isoalliin; characteristic of onion) and *S*-propyl cysteine sulfoxide (PCSO, propiin; in onion, garlic and related species). The enzyme alliinase had been reported to cleave these precursors to give pyruvate, ammonia and a thiosulfinate. The lachrymatory effect, that is, characteristic of onions was caused by the volatile product propanethial *S*-oxide (Brodnitz et al. 1971). The lachrymatory factor was reported to be generated by the activity of a second enzyme, lachrymatory factor synthase, following alliinase action on PeCSO, the major flavour precursor of onion (Imai et al. 2002). As well as CSOs, several γ-glutamyl peptide (γGP) derivatives of these flavour compounds had been detected within the *Allium* (Whitaker 1976). Over 17 types had been isolated (Granroth 1970), including γ-glutamyl-*S*-alk(en)yl glutathiones, γ-glutamyl-*S*-alk(en)yl cysteines and γ-glutamyl-S-alk(en)yl cysteine sulfoxides, all proposed to derive from glutathione (γ-glutamyl cysteinyl glycine). However they did not appear to contribute directly to flavour. Granroth (1970) confirmed that onion could hydrolyse *S*-2-carboxypropyl glutathione and that, in onion leaf tissue, *S*-2-carboxypropyl cysteine was rapidly converted to PeCSO. *S*-methylcysteine, *S*-ethylcysteine, *S*-propyl cysteine and *S*-propenyl cysteine could all be oxidised to the corresponding sulfoxide by onion leaf tissue (Granroth 1970). Methacrylate was proposed as the precursor of the allyl, propyl and propenyl groups (Granroth 1970). Whole garlic typically contains ~1 % alliin, together with (+)-*S*-methyl-L-cysteine sulfoxide (methiin) and (+)-*S*-(*trans*-1-propenyl)-L-cysteine sulfoxide. *S*-(2-Carboxypropyl)glutathione, γ-glutamyl-

S-allyl-L-cysteine, γ-glutamyl-*S*-(*trans*-1-propenyl) -L-cysteine and γ-glutamyl-*S*-allyl-mercapto-L-cysteine are also present in garlic cloves (Fenwick and Hanley 1985, Sugii et al. 1964). The primary sulfur-containing constituents in whole, intact garlic are the γ-glutamyl-*S*-alk(en)yl-L-cysteines and *S*-alk(en)yl-L-cysteine sulfoxides, including alliin. Glutathione and γ-glutamyl peptides were reported to be intermediates in the biosynthetic pathway to *S*-alk(en)yl-L-cysteine sulfoxides (flavour precursors) in *Allium sativum*, *A. cepa* and *A. siculum* (Lancaster and Shaw 1989).

All dipropenyl thiosulfinates (allicin, 1-propenyl allyl and allyl 1-propenyl) were formed at an optimum pH of 4.5–5.0 in garlic (Lawson and Hughes 1992). The methyl propenyl thiosulfinates (allyl methyl + methyl allyl and 1-propenyl methyl + methyl 1-propenyl) and dimethyl thiosulfinate were optimally formed at pH 6.5–7.0 and pH 5.5, respectively. Below pH 3.6 no thiosulfinates were formed. Neutralisation of the pH failed to restore thiosulfinate generation from garlic previously incubated at pH 3 or below. Thus, alliinase was completely and irreversibly inhibited by the acidic conditions found in the stomach. Allyl 1-propenyl thiosulfinate was the most rapidly formed, and the most unstable, thiosulfinate. The stability of the dipropenyl thiosulfinates was improved at pH 4.5 or lower. Drying garlic at 60 °C had no effect on alliin or the rate of formation of the dipropenyl thiosulfinates, but decreased *trans*-1-propenyl cysteine sulfoxide (isoalliin) and the rate of formation of the methyl thiosulfinates. The results demonstrated that there were two alliinase activities in garlic, that a stomach acid-resistant coating on garlic powder tablets was necessary for thiosulfinate release and that carefully prepared garlic powder could release similar amounts of total thiosulfinates to whole garlic cloves. Eight known dialk(en)yl thiosulfinates were found in crushed garlic: ally-2-propenethiosulfinate (allicin) the most abundant (50–90 % mol), allylmethyl thiosulfinate (3–20 % mol), *trans*-1-propenyl-2-propene thiosulfinate (5–18 % mol), methyl-2-propene thiosulfinate (1.5–8 % mol), ally-*trans*-1-propenyl thiosulfinate (1.5–2 % mol), methylmethane thiosulfinate (1–2 % mol), *trans*-1-propenylmethane thiosulfinate (1–2 % mol) and methyl-*trans*-1-propene thiosulfinate (0.5 % mol) (Block 1992; Kyung and Lee 2001; Lawson and Gardner 2005).

In blended fresh garlic, the sulfur compounds derived from alliin included allicin (diallyl thiosufinate), allyl methyl thiosulfinates, allyl-t*rans*-1-propenyl thiosulfinates and allyl sulfides; sulfur compounds not derived from alliin included γ-glutamyl-*S*-allylcysteine, γ-glutamyl-*S*- *trans*-1-propenylcysteine, γ-glutamyl-*S*-*cis*-1-propenyl cysteine and *S*-allylcysteine; non-sulfur compounds found included γ-glutamylphenylalanine and arginine (Lawson and Gardner 2005). The allyl thiosulfinates of blended fresh garlic were stable for at least 2 years when stored at −80 °C. The dissolution release of thiosulfinates from the enteric-coated garlic tablets was found to be >95 %. The bioavailability of allyl thiosulfinates from these tablets, measured as breath allyl methyl sulfide, was found to be complete and equivalent to that of crushed fresh garlic. S-Allylcysteine was stable for 12 months at ambient temperature.

Garlic was found to contain large amounts of alliin (16.63–29.10 mg/g dry weight (DW)), γ-glutamyl-S-allyl-L-cysteine (GSAC) (12.88–24.92 mg/g) and γ-glutamyl-*S*-*trans*-1-propenyl-L-cysteine (GSPC) (20.40–38.87 mg/g) (Yoo et al. 2014b). γ-Glutamyl phenylalanine (γGPA) ranged from 4.13 to 9.56 mg/g. The main organosulfur compounds in garlic were glutamyl peptides, including GSAC, GSPC and γGPA. Allicin was the major biological compound at 5.28–7.90 mg/g DW. Methiin, cycloalliin and γ-glutamyl-S-methyl-L-cysteine (GSMC) were also present in smaller amounts. Methiin and cycloalliin were present at 0.53–2.94 and 0.44–3.24 mg/g garlic (dry weight), respectively, while GSMC was found to be between 0.57 and 1.26 mg/g garlic and S-allyl-L-cysteine (SAC) 0.31–0.57 mg/g. Finally, S-*trans*-1-propenyl-l-cysteine sulfoxide (isoalliin) (0.02–0.05 mg/g) and S-*trans*-1-propenyl-L-cysteine (SPC) (0.04–0.10 mg/g) were found in trace amounts. The major chemical components of fresh garlic

were diallyl sulfides and methyl allyl sulfides. Differences in the pattern of organosulfur composition and degradation components of thiosulfinates from warm- and cool-type garlic were demonstrated by principal component analysis. A total of 21 chemical compounds were identified, including diallyl sulfides, methyl allyl sulfides and vinyldithiins. The dominant degradation compounds in cool-type garlic were diallyl disulfides at 40.53–59.27 %, while diallyl disulfides in warm-type garlic were 60.62–70.26 %. The methyl allyl sulfide content in garlic was 2.5–14.35 %. Thiosulfinate degradation compounds from garlic were propene acetaldehyde, 2-propen-1-ol, allyl mercaptan(2-propen-1-thiol), 2-butenal, allyl methyl sulfide, acetoin, dimethyl sulfide, 2,4-dimethylfuran, hexanal, diallyl sulfide, methyl allyl disulfide, *cis*-propenyl methyl disulfide, *trans*- propenyl methyl disulfide, dimethyl trisulfide, diallyl sulfide, 3-(allylthio)-propionic acid, unknown, methyl allyl trisulfide, 3,4-dihydro-3-vinyl-1,2-dithiin, 2-vinyl-4H-1,3-dithiin and diallyl trisulfide.

Garlic and onion, wild leek, had been reported to accumulate the selenium (Se) from soil, endowing the plants greater protection against carcinogenesis (Arnault and Auger 2006). Selenomethionine, selenocysteine and Se-methylselenocysteine had been identified in garlic and onion (Yang 2002; Auger et al. 2004). Gamma-glutamyl-Se-methyl-L-selenocysteine had been identified in extracts of garlic cultivated in Se-rich soil (Auger et al. 2004). However, several Se compounds from Se-enriched garlic or onion remain unidentified (Arnault and Auger 2006). Se-methyl-selenocysteine was unstable in water extract of Se-enriched garlic when the extract was prepared and stored at room temperature (Yang 2002). Specific alliinase inhibitor hydroxylamine (NHOH.HCl) effectively prevented the loss of Se-methyl-selenocysteine, which suggested that the decomposition of Se-methyl-selenocysteine may be catalysed by alliinase. Se-enriched onion also contained alliinase and Se-methyl-selenocysteine, but its Se-methyl-selenocysteine was proved to be stable in the same water extract as that of Se-enriched garlic. The existence of Se-alk(en)yl-L-cysteine selenoxides (Se-'alliins') in garlic and onion had been demonstrated (Auger et al. 2004). An additional experiment showed that *Allium* species cultivated in Se-rich soil might contain two different Se-'alliins'.

Thiacremonone (2, 4-dihydroxy-2, 5-dimethylthiophene-3-one), an antioxidant sulfur compound, was generated from high-temperature high-pressure-treated garlic (Jo et al. 2014).

Garlic Essential Oil/Volatiles

Garlic essential oil obtained from Likens–Nickerson distillation/solvent extraction contained more 2,4-dimethylfuran, 2-propen-1-ol, aniline and 3,5-diethyl-1,2,4-trithiolane than those from water and steam distillation (Yu et al. 1989). Water layer of garlic distillate contained more 3,5-diethyl-1,2,4-trithiolane and 2-propen-1-ol than its oil layer. A total of 28 volatile compounds were found including 3-vinyl-1,2-dithiocylohex-4-ene and 3-vinyl-1,2-dithiocylohex-5-ene. Typical volatiles in crushed garlic and garlic essential oil include diallyl sulfide (DAS), diallyl disulfide (DADS), diallyl trisulfide, methyl allyl disulfide, methyl allyl trisulfide, 2-vinyl-1,3-dithiin, 3-vinyl-1,2-dithiin (Fenwick and Hanley 1985) and *E*,*Z*-ajoene (Block et al. 1984). Variation in the content of thiosulfinates including allicin; diallyl, methyl allyl and dimethyl mono-, di-, tri-, tetra-, penta- and hexasulfides; the vinyldithiins; and (*E*)- and (*Z*)-ajoene were determined in fresh garlic cloves and commercial products (Lawson et al. 1991c). The thiosulfinates were found to be released only from garlic cloves and garlic powder products. The vinyldithiins 2-vinyl-3,4-dihydro-1,2-dithiin and 3-vinyl-3,4-dihydro-1,2-dithiin and (*E*)- and (*Z*)-ajoenes were found only in products containing garlic macerated in vegetable oil. The diallyl, methyl allyl and dimethyl sulfide series were the exclusive constituents found in products containing the oil of steam-distilled garlic. Typical steam-distilled garlic oil products contained about the same amount of total sulfur compounds

as total thiosulfinates released from freshly homogenised garlic cloves; however, oil-macerated products contained only 20 % of that amount, while garlic powder products varied from 0 to 100 %. Products containing garlic powder suspended in a gel or garlic aged in aqueous alcohol did not contain detectable amounts of these nonionic sulfur compounds.

Eight main constituents and 26 minor ones were identified with two unknowns in Egyptian garlic oil (Jirovetz et al. 1992). The main constituents identified were diallyl trisulfide (29.7 %), linoleic acid (12.4 %), palmitic acid (4.8 %), diallyl tetrasulfide (4.4 %), diallyl disulfide (3.2 %), myristic acid (3.1 %), diallyl sulfide (2.5 %) and methyl allyl trisulfide (2.1 %). The other components were <1 % and included dipropyl sulfide; 2, 5-dimethyl thiophene; tetrahydro-2,5-dimethyl-thiophene; methylallyl sulfide; methyl-1-propenyl-disulfide; dimethyl trisulfide; propyl allyl disulfide; methyl-1-propenyl-trisulfide; methyl propyl trisulfide; 2-methyl benzaldehyde; 3,5-diethyl-1,2,4-trithiolane; 3-vinyl-4H-1,2-dithiin; allyl-1-propenyl trisulfide; di-L-propenyl trisulfide; propyl allyl trisulfide; 2-vinyl-4H- 1,3-dithiin; methyl allyl tetrasulfide; methyl-1-propenyl tetrasulfide; allyl-1-propenyl tetrasulfide; dipropyl tetrasulfide; pentadecanone; pentadecanol; hexadecanol; pentadecanoic acid; heptadecanone; and octadecanol.

Volatiles obtained from combined GC–MS analysis of garlic juice by solid phase microextraction (SPME): dimethyl disulfide, methyl allyl disulfide, methyl propyl disulfide, methyl 1-propenyl disulfide, diallyl disulfide, allyl propyl disulfide, allyl 1-propenyl disulfide, diallyl trisulfide, lachrymatory factor E isomer, methyl 1-propenyl thiosulfinate and 1-propenyl methyl thiosulfinate, and volatiles obtained from solvent extraction: allyl 1-propenyl disulfide, methyl 1-propenyl thiosulfinate, 1-propenyl methyl thiosulfinate, 3-vinyl-[4H]-1,3-dithiin, 2-vinyl-[4H]-1,3-dithiin and allicin (Mondy et al. 2001). In garlic allicin (18) 2-propenyl thiosulfinate was dominant; decomposition of allicin afforded two isomeric cyclic compounds, 3-vinyl-[4H]-1,2-dithiin and 2-vinyl-[4H]-1,3-dithiin.

A total of 47 compounds were identified in garlic essential oil: allyl mercaptan; methyl allyl sulfide; dimethyl sulfide; diallyl sulfide; methyl allyl disulfide; 1-propenyl methyl disulfide; methyl propyl disulfide; diallyl trisulfide; butylpropenyl sulfide; cyclopentyl hexyl sulfide; *N*-morpholinomethyl isopropyl sulfide; dimethyl trisulfide; methyl allyl trisulfide; dimethyl tetrasulfide; 2,4-dimethyl-thiophene; methyl allyl thioacetate; metoxy-methyl isothiocyanate,; cyclopentathiazole; thiazole; methylthiocyclopentane; 3-(methyl-thio)penta-2,4-dione; 5-(methylthio)-4-penten -2-ol; 2-thiophenecarboxaldehyde; methyl-thiocyclohexane; 3-vinyl-1,2-dithiocyclohex-4-ene; 3-vinyl-1,2-dithiocyclohex-5-ene; 2-(1-pro-penylthio)thiophene; ethyl-2-thiopheneacetate; 4,5-dimethylisothiazole; 3-methyl-1,1-bis (methylthio)-1,3-butadiene; 1,3 benzenedithiol; benzothiophene; 3,5-diethyl-1,2,4-trithiolane; 2-ethyl-1,3-dithiane; 2-vinyl-1,3-dithiane; 2-ethylidene-1,3-dithiane; 1,3,5-trithiane; 3-methylpyridine; 2,5-dimethylpyridine; 2-butenal; 2-methyl-4-pentenal; 2,-methyl-2-butenal; 2-methylene-4-pentanone; 2-pentenal; 2-methylfuran; and 2,4-hexadienal (Calvo-Gómez et al. 2004).

Garlic bulb extract obtained from supercritical CO_2 extraction was found to contain 3-vinyl-1,2-dithiocylohex-4-ene (47.78 %), 3-vinyl-1,2-dithiocylohex-5-ene (15.33 %), diallyl disulfide (10.88 %) and diallyl trisulfide (10.4 %) as the main volatile compounds and other compounds diallyl tetrasulfide (1.78 %), methyl 2-propanol disulfide (1.66 %) and methyl 2-propanol trisulfide (1.68 %), while petroleum ether soxhlet extraction afforded methyl 2-propanol trisulfide (16.75 %), diallyl trisulfide (16.39 %), 3-vinyl-1,2-dithiocylohex-4-ene (8,195), dimethyl trisulfide (7.89 %), 2-ethylidene[1,3]dithiane (6.91 %), diallyl sulfide (5.06 %), benzene acetaldehyde (2.80 %), methyl 2-propanol disulfide (1.18 %) and diallyl tetrasulfide 0.87 %) (Hincapie et al. 2008). Three key intermediates 2-propenesulfenic and 2-propenesulfinic acids and diallyl trisulfane S-oxide, along with other reactive volatile sulfur compounds allicin and related thiosulfinates, allyl alcohol, sulfur dioxide, propene

and pyruvate as coproducts, were detected in crushed garlic (Block et al. 2010). A commercial dietary supplement containing garlic powder, which was sampled after crushing, was found to contain alliin, methiin and *S*-allylcysteine and produced allicin upon addition of water.

Although the main compositions of the essential oils of garlic obtained by solvent extraction (SE) and supercritical fluid extraction (SFE) were basically similar, their minor compositions differed quantitatively (Li et al. 2010). The extraction yield (0.78 %) of garlic by employing SE method was slightly lower than that (0.81 %) obtained by SFE, but the extraction time (42 minutes) by SE method was shorter than that (130 minutes) obtained by SFE. The compounds of garlic essential oil extracted by SFE and SE were, respectively, as follows: 3-vinyl-4H-1,2-dithiin (32.17, 31.89 %); propyl allyl disulfide (13.95,13.89 %); diallyl trisulfide (12.94, 13.31 %); dimethyl disulfide (7.44, 7.05 %); diallyl disulfide (8.02, 6.87 %); methyl allyl trisulfide (4.67, 5.02 %); 3,5-diethyl-1,2,4-trithiolane (2.62, 2.56 %); diallyl sulfide (2.30, 2.22 %); 2-vinyl-4H-1,3-dithiin (1.78, 1.10 %); methyl propyl disulfide (1.2, 1.06 %); vinylfuran (0.98,0.92 %); 1,2-epithiopropane (0.34, 0.04 %); 3-methylthio propanal (0.3, 0 %); 3-methyl-2-cyclopentene-1-thione (0.52, 0 %); methyl butyl trisulfide (0, 0.14 %); and methyl 2-propenyl disulfide (0.34, 0 %). The major components of garlic essential oil were diallyl trisulfide (33.55 %) and diallyl disulfide (28.05 %) (Kocić-Tanackov et al. 2012).

Sixteen compounds in the commercial garlic essential oil, accounting for 97.44 % of the total oil, were identified, and the main components of the essential oil of *A. sativum* were diallyl trisulfide (50.43 %), diallyl disulfide (25.30 %), diallyl sulfide (6.25 %), diallyl tetrasulfide (4.03 %), 1,2-dithiolane (3.12 %), allyl methyl disulfide (3.07 %), 1,3-dithiane (2.12 %) and allyl methyl trisulfide (2.08 %) (Zhao et al. 2013).

Over 40 constituents were detected from steam-distilled garlic essential oil, and more than 95 % were identified as sulfur-containing compounds (Shaath et al. 1995). Diallyl trisulfide, diallyl disulfide, methyl allyl trisulfide, methyl allyl disulfide and diallyl sulfide were identified as the main constituents. Studies by Ferary et al. (1996) found that *A. sativum* odours contained only thiopropanal *S*-oxide and thiosulfinates as sulfur volatiles. Volatile compounds released from microwave heating of garlic and 2,4-decadienals were identified as: sulfur dioxide; allyl mercaptan; isopropyl alcohol; hexanal; allyl alcohol; allyl sulfide; 2-pentylfuran; methyl allyl sulfide; dimethyl trisulfide; nonanal; (*E*)-2-octenal; dithio(1-propenyl)propionate; diallyl disulfide; 1,2-dithiacyclopent-3-ene; *n*-hexanethiol; methyl benzyl sulfide; dihydro-2(3*H*)-thiophenthione; 3-vinyl-4*H*-1,2-dithiin; (*E*,*Z*)-2,4-decadienal; 2-vinyl-1,3-dithiane; (*E*,*E*)-2,4-decadienal; hexanoic acid; and 2-vinyl-4H-1,3-dithiin (Chyau and Mau 1999). A total of 23 compounds were identified from these samples, among which 14 sulfide compounds, five aldehydes, two alcohols, one acid and one furan were identified. Three compounds, dithio(1-propenyl) propionate, dihydro-2(3*H*)-thiophenthione and *n*-hexanethiol, were newly found in deep-fried garlic flavour. During microwave heating, levels of most volatiles decreased as the heating time continued. 2-Pentylfuran, isopropyl alcohol, hexanal and (*E*)-2-octenal were formed from the degradation of 2,4-decadienals. Sulfur dioxide was generated predominantly from the degradation and oxidation of sulfide compounds.

Sixteen compounds were identified in garlic steam distillate: α-pinene 1.5 %, *bis* (propen-1-yl) sulfoxide 1.8 %, 1,8-cineole 6 %, diallyl sulfide 10.8 %, linalool 2.1 %, methyl allyl sulfide 1.2 %, camphor 4.6 %, isomenthone (isomer 1) 8 %, isomenthone (isomer 2) 5 %, menthol 1.5 %, 4-terpineol 1.2 %, 5-methyl-1,2,3-thiadiazole 3.1 %, pulegone 5.7 %, diallyl trisulfide 3 %, carvacrol 2.7 % and sulfur (cyclooctasulfur) 10.1 % (Attia et al. 2012).

The major peaks observed in the chromatogram of *A. sativum* extract were attributed to diallyl disulfide (8.45 mg/L), diallyl trisulfide (4.54 mg/L), methylallyl trisulfide (7.17 mg/L) and vinyldithiins (23 mg/L).

Relative concentration (weight %) of volatiles from oils of fresh garlic; cabinet-dried and ground

garlic powder; and microwave-dried and ground garlic powder were determined, respectively, as follows: methyl propyl sulfoxide (1.31, 0.49, 0.29 %), diallyl sulfide (4.38, 4.11, 3.91 %), methyl (δ)-prop-1-enyl disulfide (7.29, 6.31, 8.09 %), dimethyl trisulfide (1.83, 0.55, 0.22 %), sabinene (0.08, 0, 0 %), δ-2-carene (0.08, 0, 0.06 %), limonene (0.13, 0, 0.06 %), diallyl disulfide (20.99, 26.51, 36.72 %), allyl (*Z*)-prop-1-enyl-disulfide (0.14, 0.48, 0.18 %), allyl (*E*)-prop -1-enyl-disulfide (0.31, 0.98, 0.17 %), allyl methyl trisulfide (16.56, 9.43, 5.86 %), 2-vinyl-4H-1,3-dithiin (0.21, 2.19, 0.05 %), diallyl trisulfide (41.53, 32.89, 25.89 %), allyl methyl tetrasulfide (0.57, 1.14,1.09 %) and diallyl tetrasulfide (3.27, 11.6, 12.55 %) (Rao et al. 2007). Methanethiol, methyl thiirane, allyl methyl sulfide, dimethyl disulfide, allyl sulfide, methyl 2-propenyl disulfide, diallyl disulfide and allyl trisulfide were identified in garlic using head space solid phase microextraction/gas chromatography/mass spectroscopy (Clemente et al. 2011).

Volatile flavour compounds found in both fresh and stored Jin Xiang (JX) garlic and Tai'an (TA) garlic included 1,3-two thiophene; allyl disulfide; allyl trisulfide (allicin);diallyl tetrasulfide; 1,3-dithiane; and 3-(allylsulfanyl) propanoic acid (Shan et al. 2013). Allyl sulfide and 1,1′thiobis 1-propene were found in stored JX and TA; methyl 1-propenyl disulfide, methyl 12-propenyl disulfide and N-N-dimethyl ethanamide were found in fresh TA only; dimethyl trisulfide in stored JX and TA; 2-vinyl-1,3-dithiane and 2-ethylidene[1,3] dithiane in stored TA; dioxane and 3-aminorhodanine in stored JX and TA; methyl (allylsulfanyl) acetate in stored JX and TA; 6-(methylthio) hexa-1,5-dien-3-ol and 1,3,5-trithiane in fresh TA only; 2-mercapto-3,4-dimethyl-2,3-dihydrothiophene in stored JX and TA; 3-vinyl-3,4-dihydro-1,2-dithiane in stored JX only; 1-ethyl-2-methyl-4-pentenyl methyl ether in stored TA and fresh JX; 5-methoxy-4-methyl-1-heptene in stored JX and TA and fresh JX; 2,5-dimethyl-1,3,4-thiadiazole in stored JX only; and benzothiofuran in fresh TA garlic only.

Steroidal Saponins/Sapogenins

The steroid saponin sitosterol was found in garlic (Smoczkiewicz et al. 1982). An azurogen C steroid glycoside $C_{57}H_{96}O_{30}$ was isolated from garlic (Kravets et al. 1990). A furostanol glycoside was isolated from garlic bulb and its structure elucidated as 26-*O*-β-glucopyranosyl 22-hydroxy-25(R)-5α-furostane-3β, 6β, 26-triol 3-*O*-β-glucopyranosyl(1→2)-[β-glucopyranosyl(1→3)]-β-glucopyranosyl-(1→4)-β-galactopyranoside, i.e. proto-eruboside-B (Matsuura et al. 1988). On enzymatic hydrolysis it yielded eruboside-B. A new furostanol glycoside, named sativoside-B1, with the structure (25R)-26-*O*-β-D-glucopyranosyl-22-hydroxy-5α-furostane-3β, 6β, 26-triol 3-*O*-β-D-glucopyranosyl-(1→3)-*O*-*β*-*d*-glucopyranosyl-(1→2)-*O*-[β-d-glucopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-galactopyranoside along with proto-desgalactotigonin were isolated from garlic bulbs (Matsuura et al. 1989). From the plant roots, two new steroidal glycosides, named sativoside-R1 and sativoside-R2, were isolated, and their structures were determined to be (25R)-26-O-β-D-glucopyranosyl-22-hydroxy-5α-furostane-3β, 26-diol 3-*O*-β-D-glucopyranosyl-(1→3)-*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xylopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-galactopyranoside) and tigogenin 3-*O*-β-D-glucopyranosyl-(1→3)-*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xylopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-galactopyranoside, respectively. Besides these glycosides, three known glycosides, proto-desgalactotigonin, desgalactotigonin and F-gitonin were isolated and identified. Six compounds were isolated from the fresh garlic bulbs including two new steroidal saponins proto-iso-eruboside-B and iso-eruboside plus known sativoside-C and adenosine and tryptophan (Peng et al. 1996). Two new steroidal saponins, iso-eruboside B and sativoside-C, along with a known compound, eruboside-B2, and a new furostanol saponin, proto-iso-eruboside-B, were isolated from garlic bulb (Peng and Yao 1996).

The following steroidal furostanol saponins, proto-eruboside-B, sativoside-B1, chinenoside-I and a new compound β-chlorogenin (25*R*)-26-O-β-

D-glucopyranosyl-22-hydroxy-5α-furostane-3β, 6β, 22, 26-tetraol 3-*O*-β-D-glucopyranosyl(1→2)-*O*-[β-d-glucopyranosyl(1→3)]-*O*-β-D-glucopyranosyl(1→4)-*O*-[α-l-rhamnopyranosyl(1→2)-*O*-β-D-galactopyranoside; spirostanol saponins, eruboside-B, sativoside-B1-sp., ampeloside-Bs1, chinenoside-I-sp. and a new compound β-chlorogenin 3-*O*-β-D-glucopyranosyl(1→2)-*O*-[β-D-glucopyranosyl(1→3)]-*O*-β-D-glucopyranosyl(1→4)-*O*-[α-L-rhamnopyranosyl (1→2)]-*O*-β-D-galactopyranoside; aglycones, β-chlorogenin, agigenin and laxogenin; and a pentacyclic terpenoid derivative glycyrrhetinic acid were identified from garlic and aged garlic (Matsuura 2001). Four steroidal saponins were isolated from crude extracts of garlic and elucidated as (25S)-26-*O*-β-D-glucopyranosyl-22-hydroxy-5α-furostane-3β,6β,26-triol-3-*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-glucopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-galactopyranoside; 25S)-26-*O*-β-D-glucopyranosyl-22-methoxy-5α-furostane-3β,6β,26-triol-3-*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-glucopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-galactopyranoside; (25R)-26-*O*-β-D-glucopyranosyl-22-methoxy-5α-furostane-3β,6β,26-triol-3-*O*-β-D-glucopyranosyl-(1→3)-*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-glucopyranosyl-(1→)]-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-galactopyranoside; and (25R)-26-*O*-β-D-glucopyranosyl-22-methoxy-5α,6β-furostane-3β, 26-diol-3-*O*-β-D-glucopyranosyl-(1→2)-*O*-[β-D-xylopyranosyl-(1→3)]-*O*-β-D-glucopyranosyl-(1→4)-*O*-β-D-galactopyranoside (Ma et al. 2011).

Five cerebrosides, AS-1-1 (1), AS-1-2 (2), AS-1-3 (3), AS-1-4 (4) and AS-1-5 (5), were isolated $CHCl_3$–MeOH extract of garlic bulbs (Inagkai et al. 1998). The structures of 1–5 were elucidated as: 1-*O*-(β-D-glucopyranosyl)-(2*S*,3*R*,4*E*,8*E*)-2-[(2*R*)-2-hydroxytetradecanoylamino]-4,8-octadecadiene-1,3-diol (1); 1-*O*-(β-D-glucopyranosyl) -(2*S*,3*R*,4*E*,8*E*)-2-[(2*R*)-2-hydroxypentadecanoylamino]-4,8-octadecadiene-1,3-diol (2); 1-*O*-(β-D-glucopyranosyl)-(2*S*,3*R*,4*E*,8*Z*)-2-[(2*R*)-2-hydroxyhexadecanoylamino]-4,8-octadecadiene-1,3-diol (3); 1-*O*-(β-D-glucopyranosyl)-(2*S*,3*R*,4*E*,8*E*)-2-[(2*R*)-2- hydroxyhexadecanoylamino]-4,8-octadecadiene-1,3-diol (4); and -*O*-(β-D-glucopyranosyl)-(2*S*,3*R*,4*E*,8*E*)-2-[(2*R*)-2-hydroxyhexadecanoylamino]-4-octadecadiene-1,3-diol (5), respectively. Compounds 3 and 4 were identified with the known glucocerebroside soya-cerebroside I and II, respectively, which had been previously obtained from soybean with ionophoretic activity.

Antifungal furostanol saponins were isolated from bulbs of garlic *Allium sativum* var. Voghiera, voghieroside A1/A2 and voghieroside B1/B2, based on the rare agapanthagenin aglycone, voghieroside C1/C2; based on agigenin aglycone and voghieroside D1/D2 and E1/E2; and based on gitogenin aglycone (Lanzotti et al. 2012). In addition, two known spirostanol saponins, agigenin 3-*O*-trisaccharide and gitogenin 3-*O*-tetrasaccharide, were found. High concentrations of two eugenol diglycosides were also found for the first time in *Allium* spp.

Miscellaneous Phytochemicals

Incubations of [1-14C]linoleic acid or [1-14C]-(9*Z*,11*E*, 13*S*)-13-hydroperoxy-9,11-octadecadienoic acid (13-HPOD) with juice of garlic bulbs led to the formation of divinyl ether (9*Z*,11*E*, 1′*E*)-12-(1′-hexenyloxy)-9,11-dodecadienoic acid ('etheroleic acid') (Grechkin et al. 1995). With lesser efficiency [1-14C] α-linolenic acid or [1-14C](9*Z*,11*E*,13*S*,15*Z*)-13-hydroperoxy-9,11,15-octadecatrienoic acid (13-HPOT) was converted in this way into (9*Z*,11*E*,1′*E*,3′*Z*)-12-(1′,3′-hexadienyloxy)-9,11-dodecadienoic acid ('etherolenic acid'). Thus, garlic bulbs possessed the activity of a 13-hydroperoxide-specific divinyl ether synthase.

Antifungal N-feruloyl amides *N*-feruloyltyrosine and *N*-feruloyltyramine were isolated from *A. sativum* roots (Fattorusso et al. 1999). A new stress compound, named allixin, was isolated from garlic bulbs the structure as 3-hydroxy-5-methoxy-6-methyl-2-pentyl-4H-pyran-4-one (Kodera et al. 1989). Allixin was also induced by irradiating fresh

garlic cloves with sunlight or UV light (Kodera et al. 2001). The accumulated amounts of induced allixin were 3.1–6.3 μg/g under experimental conditions. Extremely high accumulation of allixin, a phytoalexin derived from garlic, was observed in necrotic tissue areas after long-term storage (Kodera et al. 2002a). The allixin produced recrystallised on the surface of garlic cloves. The amount of allixin produced in raw garlic with necrotic tissue areas was 1,400 ng/mg wet garlic. After approximately 2 years of storage, the amount of allixin accumulated reached slightly less than 1 % of the dry weight of garlic cloves. *N-trans*-coumaroyloctopamine, *N-trans-feruloyloctopamine*, guaiacylglycerol-β-ferulic acid ether and guaiacylglycerol-β-caffeic acid ether were identified in garlic skins as were *trans*-coumaric acid and *trans*-ferulic acid (Ichikawa et al. 2003).

Extensive in-vitro and in-vivo studies and reviews had been reported on the wide array of pharmacological properties of garlic extracts and their potential medicinal benefits in cardiovascular diseases, neurodegenerative diseases, cancers, diabetics, dermatological ailments, osteoporosis, cataract, gastrointestinal ailments and in the control of microbes, parasites, molluscs, worms and insect (Kendler 1987; Augusti 1996; Block 1997; Bianchini and Vainio 2001; Corzo-Martínez et al. 2007; Harris et al. 2001; Amagase 2006; Lanzotti 2006; Bongiorno et al. 2008; Singh and Singh 2008). These biological properties include hypocholesterolaemic, hypolipidaemic, antihypertensive, antidiabetic, antithrombotic, antihyperhomocysteinaemia effects, antimicrobial, antioxidant, anticarcinogenic, antimutagenic, antiasthmatic, immunomodulatory, insecticidal, nematicidal, rodenticidal, anthelmintic, molluscicidal and prebiotic activities. Studies suggested that oral administration of garlic was effective on immunological properties, cutaneous microcirculation, protection against UVB and cancer treatment (Pazyar and Feily 2011). Additionally, topical application of garlic extract could potentially be effective on psoriasis, alopecia areata, keloid scar, wound healing, cutaneous corn, viral and fungal infection, leishmaniasis, skin ageing and rejuvenation.

Antioxidant Activity

In-Vitro Studies

The lipid peroxidation and chemiluminescence (CL) of mouse liver mitochondria induced by a Vc/$FeSO_4$ reaction system was greatly inhibited by garlic oil and allitridin (diallyl trisulfide) at 0.1 mg/mL (Fu 1993). HpD-induced photohaemolysis was moderately inhibited by garlic oil (25 μg/mL) and allitridin (20 μg/mL). Allitridin (200 μg/mL) effectively prevented inactivation of red cell membrane acetylcholinesterase (AchEs) caused by .OH, and at 250 μg/mL it markedly inhibited blood CL stimulated by croton oil. Garlic oil (5 μg/mL) and allitridin (100 μg/mL) significantly increased O^{2-} production. Allitridin at 0.25 mg/mL and 1 mg/mL enhanced lipid peroxidation of mitochondria and blood CL caused by H_2O_2. Garlic extract (5–100 μL/mL) produced an inhibition (30–100 %) of 2,3-dihydroxybenzoic acid (2,3-DHBA) and 2,5-dihydroxybenzoic acid (2,5-DHBA) generated by photolysis of H_2O_2 in a concentration-dependent manner (Prasad et al. 1996). Garlic extract prevented the .OH-induced formation of malondialdehyde in the rabbit liver homogenate in a concentration-dependent manner. It alone did not affect the MDA levels in the absence of .OH. The results indicated garlic extract to be a powerful scavenger of .OH and that heating reduced its activity slightly. Allicin (active ingredient of garlic) contained in the commercial preparation Garlicin was found to have antioxidant activity (Prasad et al. 1995). Allicin prevented the lipid peroxidation of liver homogenate in a concentration-dependent manner. Allicin produced concentration-dependent decreases in the formation of 2,3-DHBA and 2,5-DHBA generated by H_2O_2.

Aqueous and methanol garlic extracts exhibited strong DPPH antioxidant activity (80–90 % of the standard) (Meriga et al. 2012). Garlic showed a higher DPPH free radical scavenging activity than red onion but had lower total phenolic content (37.60 mg GAE/100 g) than red onion (53.43 mg GAE/100 g) (Othman et al. 2011). However, the primary antioxidant activities of

both were lower than the standard antioxidant, BHA. Red onion had higher ferrous ion-chelating effect (i.e. 45.00 %) as compared to garlic (43.29 %) but both showed slightly higher ion-chelating effect than BHA (tert-butyl-4-hydroxyanisole) (43.14 %) but lower than EDTA (ethylenediamine tetraacetic acid) (97.9 %). Aged black garlic exhibited significantly higher phenolic content and greater antioxidative activity than fresh garlic as assessed by DPPH scavenging, ferricyanide reducing power, ferrous ion-chelating ability and inhibitory effect on linoleic acid peroxidation (Kim et al. 2012). Both garlic extracts showed strong antioxidant capacity in a dose-dependent manner.

Fanelli et al. (1998) found that diallyl disulfide (DDS), diallyl sulfide (DAS) and allyl mercaptan (AMT) but not allyl methyl sulfide (AMS) were able to trap trichloromethyl and trichloromethylperoxyl free radicals. Further, DDS but not DAS or AMT also inhibited CCL_4-promoted liver microsomal lipid peroxidation. DAS, but not DDS, AMT or AMS, was able to react with free radicals that appeared during UVC activation of hydrogen peroxide or tert-butyl hydroperoxide but not with those produced during UVC activation of tert-butyl peroxide. However, all garlic components tested absorbed energy from UVC and became partially destroyed in the process. AMT, but not DDS, AMS or DAS, was able to destroy 4-hydroxynonenal, a key reactive aldehyde produced during lipid peroxidation. AMT and DDS were also able to prevent UVC plus CCL_4-promoted oxidation of albumin in-vitro, but DAS and AMS failed to do so.

An in-vitro study in Vero cells suggested that diallyl tetrasulfide from garlic inhibited the reactive oxygen species (super oxide anion and hydrogen peroxide) generation induced by cadmium and exerted a novel protective effect on the cytolethality associated with cadmium-induced mitochondrial injury, which contributed to the antiapoptotic effect of diallyl tetrasulfide against cadmium (Murugavel et al. 2007). Average contents of alliin, vitamin C, total phenol and total flavonoid per 100 g dry weight of 19 garlic cultivars were, respectively, 1,938.4 mg, 9.3 mg, 97.0 mg gallic acid equivalent (GAE) and 16.1 mg catechin hydrate equivalent (CE), and antioxidant activity was 27.5 % (Bhandari et al. 2014). Among the three free sugars analysed, sucrose was present in the greatest quantity (3.48 %), followed by fructose (1.05 %) and glucose (0.54 %). Total flavonoid content showed the highest positive correlations with antioxidant activity ($R^2 = 0.908$), followed by total phenol and vitamin C contents. Aged garlic extract inhibited the emission of low level chemiluminescence and the early formation of thiobarbituric acid reactive substances (TBARS) in liver microsomal fraction initiated by t-butyl hydroperoxide (Imai et al. 1994). However, the water extracts of raw and heat-treated garlic enhanced the emission of low level chemiluminescence. S-allylcysteine (SAC) and S-allylmercaptocysteine (SAMC), the major organosulfur compounds found in aged garlic extract, showed radical scavenging activity in both chemiluminescence and 1,1-diphenyl-2-picrylhydrazyl (DPPH) assays, indicating that these compounds may play an important role in the antioxidative activity of aged garlic extract. Studies found the bioactive compounds, electrophoretic patterns and antioxidant potential of fresh Polish, Ukrainian and Israeli garlic samples to be comparable (Gorinstein et al. 2005). Garlic samples subjected to 100 °C during 20 minutes preserved their bioactive compounds, antioxidant potential and protein profile and were comparable with fresh garlic, and (c) fresh garlic should be added to dishes cooked at 100 °C in the last 20 minutes of the cooking process.

Garlic bulb and immature plant extracts reduced the DPPH radical formation (IC_{50} ranging from 1.03 to 6.01 mg/mL) and neutralised H_2O_2 (IC_{50} ranging from 0.55 to 2.01 mg/mL) in a dose-dependent manner (Bozin et al. 2008). Strong inhibition of lipid peroxidation in Fe^{2+}/ascorbate and Fe^{2+}/H_2O_2 systems of induction was observed for all tested garlic extracts. Various levels of phenolics (0.05–0.98 mg gallic acid equivalents/g of dry extract) and flavonoid

aglycones (4.16–6.99 μg quercetin equivalents/g of dry extract) in the investigated extracts of garlic could explain the obtained differences in these results only partially. Garlic essential oil exhibited potential to be a powerful antioxidant (Lawrence and Lawrence 2011). IC_{50} values observed for DPPH and nitric oxide scavenging assays were 0.5 mg/mL and 50 μg/mL, respectively. In reducing power assay, absorbance increased linearly with increasing concentration of the oil, and in β-carotene bleaching method also, there was 84 % bleaching in the first one hour and it decreased to 45 % by the completion of the second hour.

The methanol extracts of onion and garlic extract gave similar antioxidant activity as determined by inhibition of lipid peroxidation induced by tert-butyl hydroperoxide in isolated rat hepatocytes and scavenging activity against DPPH radical (Nuutila et al. 2003). The radical scavenging activities also correlated positively with the total phenolics of the extracts. Onions had clearly higher radical scavenging activities than garlic, red onion being more active than yellow onion. The skin extracts of onion possessed the highest activities. The lowest levels of phenolics were detected for garlic (75–700 GAE mg/kg), whereas the highest amounts of phenolics were detected for the dry skin of onions: 80,000 GAE mg/kg in red onion and 26,000 GAE mg/kg in yellow onion. Garlic did not contain quercetin or kaempferol in detectable amounts. Garlic was a much less effective inhibitor of lipid peroxidation than yellow onion. However, according to Miller et al. (2000), garlic was found to be very high in antioxidants, its activity (1300 Trolox equivalents/100 g) being about sixfold that of yellow onion (200 Trolox equivalents/100 g). The extract of garlic skins (peels) showed strong antioxidant (DPPH radical scavenging) activity, and some responsible constituents were isolated and identified (Ichikawa et al. 2003).

In-vitro studies showed four main chemical classes in garlic, alliin, allyl cysteine, allyl disulfide and allicin to have antioxidant activity (Chung 2006). Alliin scavenged superoxide, while allyl cysteine and allyl disulfide did not react with superoxide. Allicin suppressed the formation of superoxide by the xanthine–xanthine oxidase system, probably via a thiol exchange mechanism. Alliin, allyl cysteine and allyl disulfide all scavenged hydroxyl radicals. Alliin, allicin and allyl cysteine did not prevent induced microsomal lipid peroxidation, but both alliin and allyl cysteine were hydroxyl scavengers, and allyl disulfide was a lipid peroxidation terminator. Garlic aqueous extract was found to be effective in protecting against the nonsteroidal oestrogenic mycotoxin, zearalenone-induced cytotoxicity, reactive oxygen species (ROS) generation and DNA fragmentation in cultured Vero cells (Abid-Essefi et al. 2012).

Chen et al. (2013) found that the bulbs of garlic cultivar '74-x' had the highest phenolic content (total phenolic, flavonoids) and the strongest antioxidant capacity (DPPH [2, 2-diphenyl-1-picrylhydrazyl] radical scavenging activity (ferric ion reducing antioxidant power) CUPRAC), followed by bulbs of cultivar 'Hanzhong purple'; the bulbs of cultivar 'Gailiang' had the lowest phenolic content and antioxidant capacity (FRAP, CUPRAC, MCA (metal chelating activity)). The bolts of 'Hanzhong purple' also had higher phenolic content. All 8 test garlic bulb extracts successfully prevented human vascular endothelial cell death and significantly prevented reactive oxygen species (ROS) formation in oxidative stress model, in which cultivar '74-x' had the highest protection capability, following by cultivar 'Hanzhong purple', and the bulbs of cultivar 'No. 105 from Korea' had the lower protection capability against cell death and ROS formation. Extracts from garlic that sprouted for 5 days had the highest antioxidant (DPPH scavenging) activity, whereas extracts from raw garlic had relatively low antioxidant activity (Zakarova et al. 2014). Furthermore, sprouting changed the metabolite profile of garlic: the metabolite profile of garlic that sprouted for 5–6 days was distinct from the metabolite profile of garlic sprouted for

0–4 days, which supported the finding that garlic sprouted for 5 days had the highest antioxidant activity.

It was found that blanching and frying and then microwaving of garlic and onions did not decrease significantly the amounts of their bioactive compounds (polyphenols, flavonoids, flavonols, anthocyanins, tannins and ascorbic acid) and the level of antioxidant activities (Gorinstein et al. 2008). The HPLC profiles of free and soluble ester- and glycoside-bound phenolic acids showed that *trans*-hydroxycinnamic acids (caffeic, *p*-coumaric, ferulic and sinapic) were as much as twice higher in garlic than in onions. Quercetin quantity was the highest in red onion among the studied vegetables. The electrophoretic separation of non-reduced garlic and onion proteins after boiling demonstrated their degradation in the range from 50 to 112 kDa. Fresh garlic and its products, i.e. chopped with salt, chopped without salt, fried and mixed garlic (fresh garlic with dehydrated garlic), exhibited different magnitude of antioxidant activity as evaluated by three different methods: DPPH (1,1-diphenyl-2-picrylhydrazyl) assay, β-carotene/linoleic acid assay and Rancimat® method (Queiroz et al. 2009). Among all the analysed products, fried garlic presented the highest antioxidant activity. The free radical scavenging activity decreased during the shelf life of all analysed products that correlated with the decrease in the total polyphenol content.

Four flavonols and their aglycones isolated from garlic leaf and shoot exhibited in-vitro antioxidant activity (Kim et al. 2005). In the DPPH (1,1-diphenyl-β-picryl hydrazyl) radical scavenging assay, quercetin showed the highest antioxidant activity among the compounds: quercetin 88.38 %, kaempferol 61.87 %, isorhamnetin 55.03 %, isoquercitrin 54.76 %, reynoutrin 39.58 %, isorhamnetin 3-*O*-β-D-glucopyranoside 17.9 % and astragalin 3.11 % in comparison to known antioxidants BHA 24.01 % and a-tocopherol 44.12 %. In hydroxyl radical scavenging activity, quercetin and its glycosides showed the highest activity over 90 %, while kaempferol, astragalin, isorhamnetin and isorhamnetin 3-*O*-β-D-glucopyranoside showed 80–82 % activity. In linoleic acid peroxidation inhibition assay, quercetin (89.93 %) exhibited the highest activity, reynoutrin 62.28 %, isorhamnetin 63 %, kaempferol 61.9 %, isorhamnetin 3-*O*-β-D-glucopyranoside 58.62 %, astragalin 42.49 % and isoquercetin 42.09 %. In the soybean lipoxygenase assay, the IC_{50} values of quercetin, isoquercitrin and reynoutrin were 16.9, 40.1 and 32.9 μM, respectively. Quercetin was the most effective among the flavonols. In the hyaluronidase (HYA) inhibition assay, the IC_{50} values of quercetin, isoquercitrin and reynoutrin were 23.0, 20.9 and 22.1 mM, respectively. Isoquercitrin had the most potent inhibitory activity on HYA.

Animal Studies

Administration of water-soluble proteins of garlic (500 mg/kg body wt/day) to alcohol-fed rats showed significant increase in antiperoxide activity and decrease in the activity of glutathione peroxidase and glutathione s transferase as compared to a standard drug gugu-lipid (Rajasree et al. 1998). In contrast rats fed with ethanol exhibited high levels of tissue malondialdehyde, hydroperoxide and diene conjugates and decreased contents of tissue superoxide dismutase, catalase and glutathione. Both garlic oil and onion oil supplementation to nicotine-treated rats increased resistance to lipid peroxidation (Helen et al. 1999). The supplementation increased activities of antioxidant enzymes, catalase, superoxide dismutase and glutathione peroxidase and increased concentrations of glutathione. The results indicated that oils of garlic and onion were effective antioxidants against the oxidative stress. Administration of garlic extract significantly decreased lipid peroxidation in 7, 12-dimethylbenz[a]anthracene (DMBA)-induced hamster buccal pouch carcinogenesis in male Syrian hamsters and induced and restored the depletion of antioxidants ascorbic acid, vitamin E, reduced glutathione (GSH),

glutathione peroxidase (GPx), superoxide dismutase (SOD) and catalase (Balasenthil et al. 2000). Studies showed that garlic oil and that GO and three allyl compounds, diallyl sulfide (DAS), diallyl disulfide (DADS) and diallyl trisulfide (DATS), played a differential role in modulation of glutathione (GSH)-related antioxidant system in rat livers and red blood cells (Wu et al. 2001). DATS displayed a greater enhancement than GO and DADS in increasing GSH content. In rat livers, DADS and DATS significantly increased the activity of GSH reductase (46 and 54 %, respectively) and of GSH S-transferase (GST) (63 and 103 %, respectively), but decreased the GSH peroxidase activity (27 and 28 %, respectively). In contrast, GSH reductase and GST activities in the DAS group were similar to the control group. An increase in GST activity and a decrease in GSH peroxidase activities were also noted in garlic oil-treated rats. In red blood cells, three GSH-related antioxidant enzyme activities were not affected by garlic oil and its organosulfur components.

Supplementation of the beef tallow diet of mice with red pepper (*Capsicum annuum*) or garlic suppressed plasma triacylglyceride level (Kuda et al. 2004). Red pepper lowered caecal Bacteroidaceae, a predominant bacterial group (from 9.4 to 9.0 log CFU/g), *Bifidobacteria* (from 8.7 to 7.6 log CFU/g) and Staphylococci, but garlic did not evoke significant changes in caecal microflora. Gorinstein et al. (2006a, b) showed that raw and boiled garlic at 100 °C for 20 minutes improved the plasma lipid levels in rats fed with cholesterol-containing diets and increased the plasma antioxidant activity (evaluated by cupric-reducing antioxidant capacity and Trolox equivalent antioxidant capacity assays) in groups of rats fed with cholesterol-free diets. Garlic boiled for a short time can be used as an additive in cooking. Supplementation of garlic at the dose of 500 mg (25 mg of lyophilised garlic/kg body weight) to the basal diet of rats was chosen as the most effective in terms of in-vivo plasma antioxidant activity and decrease of plasma lipids and fibrinogen (Jastrzebski et al. 2007). In-vitro antioxidant capacity measured by the ferric ion reducing antioxidant power (FRAP) method and by the 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical assay was the highest in raw and in a short time processed garlic samples by cooking. The contribution of total polyphenols to the antioxidant activities of raw and cooked garlic was high (R^2 from 0.997 for FRAP and to 0.975 for DPH).

Studies showed that rats fed with diets of garlic or onions could reduce the exercise-induced oxidative stress but does not alter plasma cholesterol profile (Choi and Cho 2006). In garlic- or onion-fed animals, the ratio of reduced glutathione/oxidised glutathione was significantly higher than those of the control animals before and after exercise. The level of liver malondialdehyde (MDA) was lower than that of control animals after exercise. Compared to control animals, catalase activity of garlic-fed animals was higher before exercise but was lower after exercise, while superoxide dismutase (SOD) activity of garlic-fed animals was lower in before and after exercise. Catalase activity of onion-fed animals was higher before and during exercise, while SOD activity was higher during exercise. Plasma cholesterol profiles were not significantly different in rats fed with different *Allium* vegetable diets. The results suggested that *Allium* vegetable diets had antioxidative activities and could reduce the oxidative stress from exercise in rats but did not alter the plasma cholesterol profile.

Clinical Studies

In a clinical study of 25 healthy volunteers, 2 months intake of garlic tablets reduced malondialdehyde (MDA) level by about 60 % of the initial value (Grune et al. 1996). The MDA reducing effect was found in all age groups. The reduced GSH concentration in circulating human erythrocytes showed a significant increase after the 2-month period of garlic application, while the oxidised glutathione (GSSG) concentration showed no significant changes. Thus a significantly decreasing trend of the GSSG–total glutathione ratio was determined.

Anticancer Activity

In-Vitro Studies

Garlic powder failed to inhibit the growth of human hepatoma HepG2 or human colorectal carcinoma Caco-2 cells at concentrations of up to 1,000 µg/mL (Siegers et al. 1999). Garlic extract, in which the alliin content was highly enriched, was also unable to inhibit the growth of these cells. However, when the garlic extract was supplemented with garlic powder (to 10 % final concentration), there was a concentration-dependent clear inhibition of tumour cell growth (IC_{50} values of 330 µg/mL for HepG2 and 480 µg/mL for Caco-2 cells). The growth of the human lymphatic leukaemia cell line CCRF CEM was significantly inhibited in a dose-dependent manner by both garlic powder and garlic extract at concentrations as low as 30 µg/mL.

A single p.o. pretreatment of male rats with diallyl sulfide (DAS), a component of garlic oil, caused a significant decrease in the oxidative metabolism of N-nitrosodiethylamine (NDEA) and 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK) in rat nasal mucosa (Hong et al. 1991). Whereas the nasal metabolism of N-nitrosodimethylamine (NDMA) was reduced by DAS pretreatment, there was no change in the amount of the nasal microsomal proteins immunoreactive with the antibodies against hepatic cytochrome P450IIE1. The inhibitory effect of DAS on the nasal oxidative metabolism of NDMA, NDEA and NNK was also observed in experiments in-vitro. The results demonstrated the ability of nasal mucosa to metabolically activate these nitrosamine carcinogens and the inhibition of this process by DAS, suggesting that DAS may be effective in inhibiting the related nasal tumorigenesis. DAS pretreatment significantly decreased the incidence of NNK-induced lung tumours (37.9 vs. 100 %) and the tumour multiplicity (0.6 vs. 7.2 tumours/mouse) in comparison to the vehicle control group (Hong et al. 1992). It was found that the chemopreventive effect of DAS against NNK-induced lung tumorigenesis in A/J mouse was probably by inhibiting the metabolic activation of NNK. Addition of 10 µM diallyl trisulfide (DATS) reduced human neoplastic lung cell (A549) growth by 47 %, whereas 10 µM diallyl disulfide (DADS) decreased growth by only 20 % (Sakamoto et al. 1997). DATS treatment (10 µM) did not alter nonneoplastic (MRC-5) lung cell growth. DATS (10 µM) caused a marked and progressive increase in intracellular Ca2+ in A549 cells during the first 4 hours after treatment. Exposure to 1 µM DATS for 24 hours significantly induced apoptosis, as indicated by increased DNA fragmentation.

S-allylcysteine (SAC), from garlic extract, inhibited proliferation of nine human and a murine melanoma cell line in a dose-dependent manner (1.2–10 mM) (Takeyama et al. 1993). SAC inhibited cellular growth and proliferation and modulated major cell differentiation markers of melanoma. Garlic extract induced a significant in-vitro cytotoxic activity on Sk-mel3 melanoma cell line (Hakimzadeh et al. 2010). *S*-allylcysteine (SAC) inhibited the proliferation and differentiation of LA-N-5 human neuroblastoma cells in-vitro in a time- and dose-dependent manner (Welch et al. 1992). However, the apparent inability of this compound to induce differentiation in neuroblastoma cells may limit its therapeutic potential. *S*-allylcysteine (SAC) and *S*-allylmercaptocysteine (SAMC) exhibited antiproliferative effects in-vitro on human breast cancer cells, MCF-7 and an aggressive, oestrogen-independent form MCF-7(ras) (Li et al. 1995). They altered the glutathione level without significant concurrent changes in the glutathione-metabolising enzymes. *S*-Allylmercaptocysteine, a garlic derivative, was shown to inhibit vascular smooth muscle and umbilical endothelial cell proliferation (Lee et al. 1994). Inhibition was dose dependent and affected smooth muscle cells more than endothelial cells. *S*-Allylmercaptocysteine to inhibit malignant cells could also reduce the proliferation of normal cells. *S*-Allylmercaptocysteine (SAMC) inhibited growth, arrests cells in G(2)-M and induces apoptosis in two human colon cancer cell lines, SW-480 and HT-29 (Shirin et al. 2001). SAMC exerted antiproliferative effects by binding directly to tubulin and disrupting the microtubule assembly, thus arresting cells in

mitosis and triggering JNK1 and caspase-3 signalling pathways that led to apoptosis (Xiao et al. 2003).

Malignant cancer cell lines gastric (AGS) and breast (MCF-7) cells were sensitive in-vitro to garlic extracts (Ghazanfari et al. 2011). Garlic extract inhibitory effects were found to be tumour specific and dose dependent. Black garlic extract (BGE) could have significant inhibitory action on the growth of lung cancer Lewis cells (Yang et al. 2013). The combination of BGE and radiotherapy (by 60Co gamma) significantly induced Lewis cells' apoptosis in G2/M stage, decreased the expression of Bcl-2, and upregulated the expression of bax. Garlic could not only induce apoptosis but also autophagy in cancer cells (Chu et al. 2013). Autophagy, also called type-II programmed cell death, provides new strategy in cancer therapy.

Diallyl disulfide (DADS) was more effective in inhibiting the growth of human colon tumour cells (HCT-15) than isomolar concentrations of S-allylcysteine, dipropyl disulfide (DPDS), allyl chloride, allyl glycidyl ether and allyl alcohol (Sundaram and Milner 1996a). A positive correlation ($R^2 = 0.944$) was found between DADS-induced DNA fragmentation and its ability to increase intracellular free calcium levels. The widespread effectiveness of DADS was evident by its ability to inhibit the growth of human colon (HCT-15), skin (SK MEL-2) and lung (A549) tumour cell lines. Addition of DADS (100 μM) was cytostatic to all three cell lines (Sundaram and Milner 1996b). Treatment with DADS also resulted in a dose-dependent increase in intracellular free calcium in cells. Alterations in calcium haemostasis were likely involved in the growth inhibition/cytotoxicity caused by DADS. Diallyl disulfide (DADS), an oil-soluble allyl sulfur compound found in processed garlic, markedly suppressed p34(cdc2) kinase activity and induced a G(2)/M phase arrest in cultured human colon tumour (HCT-15) cells (Knowles and Milner 1998). The ability of DADS to inhibit p34(cdc2) kinase activation occurred because of decreased p34(cdc2)/cyclin B(1) complex formation and modest p34(cdc2) hyperphosphorylation (Knowles and Milner 2000). They found that alterations in cell cycle, DNA repair and cellular adhesion factors accompanied DADS exposure and may also be involved in mediating the block in G(2)/M progression (Knowles and Milner 2003). Jo et al. (2008) found that with the dynamic expression of cyclin B1, DADS induced reversible cell cycle arrest in the G2/M phase of HCT-116 colon cancer cells through a p53-independent mechanism. In HCT-116 colon cancer cells, p53-independent cell cycle arrest at G2/M phase was observed with DADS treatment, along with time-dependent increase of cyclin B1 (Song et al. 2009). In addition, apoptosis was also observed upon 24 hours DADS treatment accompanied by activation of p53. In HCT-116 cells, DADS application induced a dose-dependent increase and time-dependent changes in ROS production. The results suggested that ROS triggered the DADS-induced cell cycle arrest and apoptosis and that ROS were involved in stress-induced signalling upstream of p53 activation. Allicin exerted a time- and dose-dependent cytostatic effect on colon cancer cell lines HCT-116, LS174T, HT-29 and Caco-2 colon cancer cell lines HCT-116, LS174T, HT-29 and Caco-2 at concentrations ranging from 6.2 to 310 μM (Bat-Chen et al. 2010). Treatment with allicin resulted in HCT-116 apoptotic cell death. Allicin also induced translocation of NF-E2-related factor 2 (Nrf2) to the nuclei of HCT-116 cells. Aged black garlic extract inhibited the growth and induced apoptosis in HT29 colon cancer cells through the inhibition of the PI3K/Akt pathway, suggesting that it may be effective in the prevention and treatment of colon cancer in humans (Dong et al. 2014).

Hepatocellular carcinoma cell line HepG2 and colon cancer cell line SW620, treated with MAPK inhibitors and S-allylmercaptocysteine (SAMC) from garlic, an increased apoptosis rate, was observed (Tong et al. 2014). A significantly lower apoptosis rate was noted in the SW620 cell line (with an imperfect TGF-β signal) than the rate noted in the HepG2 cell line (with an intact TGF-β signal); it was concluded that SAMC induced the apoptosis of cancer cells by activating the TGF-β signalling pathway, after MAPK signalling was inhibited. Allicin induced cell

cycle arrest of human gastric cancer cell lines, MGC-803 and SGC-7901, in the M phase by upregulating the expression of p21WAF1 and p16INK4 genes (Ha and Yuan 2004). Allicin dose dependently inhibited proliferation of human gastric cancer SGC7901 cells by arresting the cell cycle at the G2/M phase and induction of apoptosis (Tao et al. 2013). In-vitro studies indicated that the inhibitory effects of diallyl disulfide (DADS) on human gastric adenocarcinoma AGS cell motility and invasiveness were associated with increased tightness of the tight junctions and inhibition of metalloproteinase (TIMP)-1 and metalloproteinase (TIMP)-2 mRNA levels and proteins (Park et al. 2012b). Additionally, DADS repressed the levels of claudin proteins (claudin-2, claudin-3 and claudin-4), major components of TJs, that play key roles in control and selectivity of paracellular transport.

Treatment with diallyl trisulfide (DATS) resulted in significantly inhibited U937 leukaemia cell growth in a concentration- and time-dependent manner by induction of apoptosis (Choi and Park 2012). Cytotoxicity caused by DATS was mediated by generation of ROS and subsequent activation of the ROS-dependent caspase pathway in U937 leukaemia cells. Garlic oil (2.5 and 10 μM) inhibited the proliferation of three human pancreatic cancer cell lines AsPC-1, PANC-1 and Mia PaCa-2 cells in-vitro (Lan et al. 2013). Moreover, due to programmed cell death, cell cycle arrest or both, pro-apoptosis effects on AsPC-1 cells were induced by garlic oil in a dose- and time-dependent manner.

Nishino et al. (1990) demonstrated that allixin, phytoalexin of garlic, exerted an anti-promoting activity against skin tumours induced by 12-*O*-tetradecanoylphorbol-13-acetate. Organosulfur compounds (OSC) from garlic and onions, namely, diallyl sulfide, diallyl trisulfide, allyl methyl sulfide, allyl methyl trisulfide and dipropyl sulfide, had enhancing effects on glutathione S-transferase placental (GST-P) form-positive foci formation induced by diethylnitrosamine (Den) in the liver of male F344 rats (Takada et al. 1994a, b). In contrast, high doses of methyl propyl disulfide and propylene sulfide significantly decreased the number of GST-P form-positive foci. To investigate the mechanism of the modifying effect on hepatocarcinogenesis, ornithine decarboxylase activity was measured in diallyl sulfide-, allyl methyl sulfide- and dipropyl sulfide-treated liver tissue without prior initiation with diethylnitrosamine, and its activity was increased compared to controls. The results suggested that the promoting effect could be caused by increased cell proliferation with increased polyamine biosynthesis. In subsequent studies, oil-soluble OSCs such as methyl propyl disulfide and propylene sulfide demonstrated inhibitory effects on the development of GST-P positive foci induced by DEN, N-methyl-N-nitrosourea, N-butyl-N-(4-hydroxybutyl) nitrosamine, N,N′-dimethylhydrazine and dihydroxydipropylnitrosamine (Fukushima et al. 1997). Moreover, water-soluble OSCs such as S-methylcysteine and cysteine similarly decreased GST-P focus formation. In contrast, OSCs such as diallyl sulfide, diallyl trisulfide and allyl methyl trisulfide enhanced the formation of such altered hepatocellular foci. Inhibitory potential for colon and renal carcinogenesis was observed in rats treated with diallyl disulfide. Thus, the results indicated that some OSCs exerted chemopreventive effects on chemical carcinogenesis but may also demonstrate promotion potential, depending on the organ examined.

Garlic oil inhibited cyclin E expression in routinely cultured human gastric adenocarcinoma SGC7901 cells and also in transforming growth factor alpha (TGF-α)-treated ones, suggesting that garlic oil inhibited the TGF-α autocrine and paracrine loops, thus suppressing cancer cell proliferation (Liang et al. 2007). Garlic oil administration for 21 weeks significantly inhibited the increase of the nodule incidence and average nodule number per nodule-bearing liver induced by N-nitrosodiethylamine (NDEA), improved hepatocellular architecture and dramatically inhibited NDEA-induced elevation of serum biochemical indices (alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase and gamma-glutamyl transpeptidase) and hepatic 8-hydroxy-2′-deoxyguanosine (8-OHdG) levels in a dose-dependent manner (Zhang et al. 2012a). Garlic oil counteracted NDEA-induced oxidative

stress in rats illustrated by the restoration of glutathione (GSH), superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR), glutathione peroxidase (GPx) and glutathione S-transferase (GST) levels and the reduction of the malondialdehyde (MDA) levels in liver. The data suggested that garlic oil exhibited significant protection against NDEA-induced hepatocarcinogenesis, which might be related with the enhancement of the antioxidant activity and the induction of apoptosis. Further, they found that garlic oil attenuated nitrosodiethylamine-induced hepatocarcinogenesis by modulating the metabolic activation and detoxification phase I (including cytochrome P450 enzyme (CYP) 2E1, CYP1A2 and CYP1A1) and phase II enzymes (including glutathione S-transferases (GSTs) and UDP-glucuronosyltransferases (UGTs)) (Zhang et al. 2013a).

Ajoene was one of the main compounds formed from heating crushed garlic as a mixture of *E*- and *Z*-isomers (*E*- and *Z*-4,5,9-trithiadodeca-1,6,11-triene 9-oxide) (Kaschula et al. 2010). Structure–activity studies on ajoene and ajoene analogues revealed that the *Z*-isomer was moderately more active than the *E*-isomer at inhibiting the in-vitro tumour cell growth, suggesting that specific protein interactions may be important. Substitution of the terminal end allyl groups in ajoene for alkyl, aromatic or heteroaromatic groups produced some analogues with superior in-vitro anticancer activity to ajoene. *Z*-ajoene exhibited antitumour properties via pro-apoptotic and cell cycle blockage activities on various cell lines involving activation of the p53 family gene products, p53, p63 and p73, at indicated doses (Terrasson et al. 2007). According to its known anti-proteasome activity, *Z*-ajoene induced a downregulation of MHC class I expression at the surface of treated cells but did not impair their recognition by $CD8^+$ T cells. A tumourigenic lymphoid cell line derived from a Burkitt lymphoma (BJA-B) was found to be more sensitive in-vitro to ajoene than human primary fibroblasts (FS4), a permanent, non-tumourigenic cell line derived from baby hamster kidney cells (BHK21) (Scharfenberg et al. 1990). Ajoene and diallyl sulfide (DAS), two garlic compounds, at 100 mg/ mL inhibited [3H] aflatoxin B1 binding to calf thymus DNA and adduct formation (Tadi et al. 1991a). They decreased the formation of both organosoluble and water-soluble metabolites of [3H]AFB1. Neither compound significantly affected glutathione S-transferase (GST) activity. The results indicated that ajoene and DAS affected AFB1 metabolism and DNA binding by inhibiting phase I enzymes and may therefore be considered as potential cancer chemopreventive agents. Ajoene inhibited both primary tumour growth and metastasis of B16/BL6 melanoma cells in C57BL/6 mice (Taylor et al. 2006). Ajoene also inhibited tumour–endothelial cell adhesion, as well as the in-vivo TNF-α response to lipopolysaccharide.

Studies suggested that ajoene might induce apoptosis in human leukaemic cells via stimulation of peroxide production and activation of nuclear factor-κB (Dirsch et al. 1998a, b). In promyelocytic leukaemia cell HL60, garlic and onion oils showed marked antineoplastic effects representing both growth suppression and differentiation activities (Ariga et al. 2000). Incubation of human promyelocytic leukaemia cells with garlic or onion oil (20 μg/mL) caused a marked suppression of HL-60 proliferation; the suppression was almost identical with those obtained by all-*trans*-retinoic acid (ATRA) or dimethyl sulfoxide (DMSO) used as positive controls (Seki et al. 2000). These oils induced the generation of nitroblue tetrazolium (NBT)-reducing activity, and about 20 % of the HL-60 cells became NBT positive. CD11b, another marker of the differentiation of these cells, was also significantly induced by garlic oil or onion oil. The data suggested that garlic and onion oils had the ability to induce differentiation of HL-60 cells into those of the granulocytic lineage. Ajoene-induced cell death in human promyeloleukaemic cells was found not to require the activation of c-Jun NH(2)-terminal kinase (JNK) but was found to be enhanced by the inhibition of extracellular signal-regulated kinases (ERK) ½ (Antlsperger et al. 2003).

Results of in-vitro studies indicated that apoptosis in leukaemia HL-60 cells triggered by ajoene was based on the activation of a

mitochondria-dependent caspase cascade which included also the activation of the initiator caspase-8 (Dirsch et al. 2002).

Z-ajoene, a sulfur-rich compound purified from garlic, induced time- and dose-dependent apoptosis in human promyelocytic leukaemia HL-60 cells (Li et al. 2002b). The transmission of apoptotic signal induced by *Z*-ajoene involved a reactive oxygen species-dependent pathway leading to caspase-dependent Bcl-2 cleavage. Antiproliferative activity of *Z*-ajoene was demonstrated against a panel of human tumour cell lines with IC_{50} values varying from 5.2 to 26.1 mM and at a lower extent in normal marsupial kidney cells (PtK2) (Li et al. 2002a). Meanwhile, *Z*-ajoene arrested HL60 cells in G(2)/M phase of cell cycle in a dose- and time-dependent way. In PtK2 cells, exposure to 20 microM *Z*-ajoene for 6 hours induced a complete disassembly of the microtubule network that was associated with an increased number of cells blocked in early mitotic stages. In-vitro, a reversible inhibition of the microtubule protein assembly was observed with an IC_{50} of 25 μM *Z*-ajoene. In-vivo, *Z*-ajoene inhibited tumour growth by 38 % and 42 % in mice grafted with sarcoma 180 and hepatocarcinoma 22, respectively. In-vitro activities of 20S proteasome purified from human erythrocytes on fluorogenic peptide substrates specific for trypsin-like, chymotrypsin-like and peptidylglutamyl peptide-hydrolysing activities revealed that ajoene inhibited the trypsin-like activity in a dose- and time-dependent manner (Xu et al. 2004). Further, the ability of 20S proteasome to degrade the OVA(51-71) peptide, a model proteasomal substrate, was partially but significantly inhibited by ajoene. In addition, when human leukaemia cell line HL60 was treated with ajoene, both trypsin- and chymotrypsin-like activities were affected, and cells arrested in G2/M phase and total amount of cytosolic proteasome increased.

The following steroidal saponins and sapogenins isolated from garlic and related *Allium* species inhibited TPA (tissue plasminogen activator)-enhanced ^{32}P incorporation into phospholipids of HeLa cells: eruboside-B (39.4 % inhibition), sativoside-B1 (4 %), sativoside-B1-sp. (19.2 %), agigenin (20.8 %), ampeloside-Bs1 (32 %), laxogenin (43 %), chinenoside-I (4.2 %), chinenoside-I-sp. (51 %) and the terpenoid glycyrrhetinic acid (30.9 %) (Matsuura 2001). Eruboside-B exhibited in-vitro cytotoxic activity against several cancer cell lines with the following ED_{50} values (μg/mL): BC1 human breast cancer (3.6 μg/mL) Lu1 human lung cancer (1 μg/mL), Col2 human colon cancer (1 μg/mL), KB human oral epidermoid cancer (12.7 μg/mL), KB-V (+VLB) drug-resistant KB assessed in the presence of vinblastine (9 μg/mL) and KB-V (−VLB) and drug-resistant KB assessed in the absence of vinblastine (8.7 μg/mL). The results of in-vitro studies revealed that 95 % of HeLa cervical cancer cells were killed at a dose of 500 μL aqueous garlic extract, whereas about 92, 87, 60 and 24 % cancer cells were killed at doses of 400, 300, 200 or 100 μL of, respectively, Islam et al. (2011).

Oil-soluble organosulfur compounds (diallyl sulfide, diallyl disulfide and diallyl trisulfide) markedly inhibited growth of canine mammary tumour cells (CMT-13) in culture but not water-soluble organosulfur compounds (S-allylcysteine, S-ethylcysteine and S-propylcysteine) (Sundaram and Milner 1993). Increasing addition of diallyl disulfide (DADS) resulted in a progressive decrease in CMT-13 cell growth. The inhibitory effects of these compounds were modified by intracellular glutathione. Diallyl trisulfide (DATS) inhibited oestrogen receptor-α (ER-α) activity in human breast cancer cells (Hahm and Singh 2014). Exposure of MCF-7 and T47D cells to DATS resulted in downregulation of ER-α protein, which peaked between 12- and 24-hour posttreatment. DATS was relatively more effective in suppressing ER-α protein expression compared with its mono and disulfide analogues. DATS treatment caused a decrease in protein levels of peptidyl-prolyl *cis-trans* isomerase (Pin1) and overexpression of Pin1 partially attenuated ER-α downregulation by DATS. The dose of S-allylmercaptocysteine (CySSA) from garlic or S-1-propenylmercaptocysteine (CySSPe) (the major onion analogue) alone required to reduce viable breast cancer MCF-7 cells by 50 % was >400 μM, (Zhang et al. 2014). This was

synergistically reduced to 62 μM and 91 μM for CySSA+Se and CySSPe+Se in the presence of Na_2SeO_3 (Se), respectively, at molar ratios of 39:1. Apoptosis was confirmed and cell cycle arrest occurred at the G2/M and sub-G1 interphases.

Allicin inhibited the growth of cancer cells of murine and human origin by inducing the formation of apoptotic bodies, nuclear condensation and a typical DNA ladder in cancer cells (Oommen et al. 2004). Also allicin induced the activation of caspase-3, caspase-8 and caspase-9 and cleavage of poly(ADP-ribose) polymerase. The protein alliumin, isolated from garlic bulb, exerted antiproliferative activity towards leukaemia L1210 cells (Xia and Ng 2005). However, it was devoid of ribonuclease activity, protease activity, mitogenic activity towards mouse splenocytes and antiproliferative activity towards hepatoma Hep G2 cells.

Diallyl sulfide (DAS) and diallyl disulfide (DADS) treatment of both H460 and H1299 cells non small cell lung cancer cells (NSCLC) resulted in the highest numbers of cells in apoptotic state (Hong et al. 2000). DADS was found to be more effective in inducing apoptosis on NSCLC. The results demonstrated that DAS, DADS and garlic extract are effective in the reduction of antiproliferative gene in NSCLC and suggested that the modulation of apoptosis-associated cellular proteins by DAS, DADS and garlic extract may be the mechanism for apoptosis. Diallyl sulfide (DAS) and diallyl disulfide (DADS) dose dependently inhibited arylamine N-acetyltransferase (NAT) activity in a human colon tumour (adenocarcinoma) cell line (Chen et al. 1998). The viability, arylamine N-acetyltransferase activity and N-acetyl-2-aminofluorene (2-AAF)-DNA adduct formation in human bladder tumour cells, was inhibited by diallyl sulfide (DAS) and diallyl disulfide (DADS) in a dose-dependent manner (Chung 1999). The data also indicated that DAS and DADS decreased the apparent values of Km and Vmax from human bladder tumour cells in both systems examined. Diallyl disulfide (DADS), one of the major components of garlic, induced cell cycle arrest and apoptosis in T24 human bladder cancer cells in-vitro (Lu et al. 2004). DADS also promoted caspase-3 activity after exposure which led to induce apoptosis. DADS also increased the product of intracellular hydrogen peroxide. DADS also increased cyclin E and decreased CDK2 gene expression which may lead to the G2/M arrest of T24 cancer cells. Diallyl disulfide (DADS) exerted antineoplasm activity in-vitro (Yu et al. 2005). DADS inhibited N-acetyltransferase activity and gene expression in human oesophagus epidermoid carcinoma CE 81T/VGH cells in a dose-dependent manner. Diallyl disulfide (DADS) treatment of colonic adenocarcinoma cells (HT-29) initiated a cascade of molecular events characteristic of apoptosis that included a decrease in cellular proliferation, translocation of phosphatidylserine to the plasma membrane outer layer, activation of caspase-3 and caspase-9, genomic DNA fragmentation and G2/M phase cell cycle arrest (Altonsy and Andrews 2011). Short-chain fatty acids (SCFAs), particularly butyrate (abundantly produced in the gut by bacterial fermentation of dietary polysaccharides), enhanced colonic cell integrity but, in contrast, inhibited colonic cancer cell growth. Combining DADS with butyrate augmented the apoptotic effect of butyrate on HT-29 cells. Administration of diallyl disulfide (DADS) to colonic adenocarcinoma cell line (Caco-2) significantly increased the number of dead cells, exhibited morphological changes characteristic to apoptosis and induced caspase-3 cleavage but not caspase-8 (Altonsy et al. 2013). DADS induced membrane FAS expression, at the transcriptional level. The results suggested that DADS induced apoptosis in colonic cancerous cells not only through the intrinsic pathways but also through enhancing the extrinsic pathway.

Studies showed that *S*-allylmercaptocysteine (50 mg/L) reduced human prostate carcinoma (LNCaP) cell growth, whereas the antiproliferative effect of *S*-allylcysteine was not as pronounced (Pinto et al. 1997). Both *S*-allylmercaptocysteine and *S*-allylcysteine caused an increase in LNCaP cell reduced glutathione concentrations. Putrescine and spermine concentrations decreased, and spermidine increased 3 days after *S*-allylmercaptocysteine

treatment. Diminished cell growth and altered polyamine concentrations suggested that *S*-allylmercaptocysteine may impede the polyamine synthesising enzyme, ornithine decarboxylase. Separate studies showed that DADS inhibited the growth of prostate cancer cells in a dose-dependent manner, compared to the control (Arunkumar et al. 2006). At 25 and 40 μM concentrations, DADS induced cell cycle arrest at G2/M transition in PC-3 cells by downregulating CDK1 expression.

S-allylmercaptocysteine (SAMC), a stable organosulfur compound of aged garlic extract, induced dose-dependent growth inhibition of two erythroleukaemia cell lines, with a 50 % lethal dose of 0.046 mM for OCIM-1 cells and 0.093 mM for HEL cells (Sigounas et al. 1997). DNA showed fragmentation compatible with apoptosis. Flow cytometric analyses of DNA revealed an abnormal cell cycle progression in both types of erythroleukaemia cells, with the major portion of the unsynchronised cells in the G2/M phase. Two main water-soluble constituents of the garlic, S-allylcysteine (SAC) and S-allylmercaptocysteine (SAMC), were able to suppress invasive androgen-independent prostate cancer (PCa) cell proliferation and invasive abilities (Chu et al. 2006). This inhibitory effect was associated with the induction of mesenchymal to epithelial transition. Most importantly, the SAC and SAMC treatment led to restoration of *E*-cadherin expression at transcription and protein levels. Furthermore, examination of cell lines from other types of cancer (ovarian, nasopharyngeal and oesophageal carcinomas) also confirmed that the effect of SAC and SAMC on activation of *E*-cadherin might be a general effect on human cancer cells. In other studies, inhibitory effects of diallyl disulfide (DADS) on LNCaP prostate cancer cell motility and invasiveness were found to be associated with increased tightness of the tight junctions, which was demonstrated by an increase in transepithelial electrical resistance (Shin et al. 2010). DADS repressed the levels of the claudin proteins, major components of tight junctions that played a key role in control and selectivity of paracellular transport. Furthermore, the activities of matrix metalloproteinase (MMP)-2 and -9 in LNCaP cells were dose dependently inhibited by treatment with DADS, and this was also correlated with a decrease in expression of their mRNA and proteins. The study indicated that tight junctions and MMPs were critical targets of DADS-induced anti-invasiveness in human prostate cancer LNCaP cells. **S**-allylcysteine (SAC) suppressed the proliferation of androgen-independent human prostate cancer (PC-3) and led to cell cycle arrest at the G0/G1 phases, as well as inducing cell apoptosis which was accompanied by the decreased expression of Bcl-2 and increased expression of Bax and caspase-8 (Liu et al. 2012b).

Diallyl sulfides, organosulfur compounds isolated from garlic, selectively inhibited the activities of mammalian family X DNA polymerases (pols), such as pol β, pol λ and terminal deoxynucleotidyl transferase (TdT), in-vitro (Nishida et al. 2008). The purified fraction consisted of diallyl trisulfide, diallyl tetrasulfide and diallyl pentasulfide (molecular ratio: 5.3:3:1). The suppression of human cancer cell (promyelocytic leukaemia cell line, HL-60) growth had the same tendency as the inhibition of pol X family among the compounds. Diallyl sulfides were suggested to bind to the pol β-like region of family X pols. Treatment of T24 human bladder cancer cells with diallyl trisulfide (DATS), compound of garlic, resulted in potent antiproliferative activity in-vitro (Shin et al. 2014). Additionally, some typical apoptotic characteristics, such as chromatin condensation and an increase in the population of sub-G1 hypodiploid cells, were observed. The results suggested that the pro-apoptotic activity of DATS was probably regulated by a caspase-dependent cascade through the activation of both intrinsic and extrinsic signalling pathways, which was mediated through the blocking of PI3K/Akt and the activation of the JNK pathway. Diallyl trisulfide (DATS)-induced apoptosis of pancreatic cancer cells (Capan-2) and non-tumourigenic pancreatic ductal epithelial cells (H6C7) (Ma et al. 2014). DATS-induced apoptosis was markedly elevated in Capan-2 cells compared with H6C7 cells. DATS-induced apoptosis was correlated with

downregulation of Bcl-2, Akt and cyclin D1 protein levels, and upregulation of Bax, Fas, p53 and cyclin B protein levels in Capan-2 cells. DATS inhibited the viability of primary colorectal cancer cells in a time- and dose-dependent manner (Yu et al. 2012). DATS induced apoptotic cell death in human primary colorectal cancer cells through a mitochondria-dependent signalling pathway. In basal carcinoma cancer cells, DATS exerted chemopreventive potential via ER stress and the mitochondrial pathway (Wang et al. 2012a).

S-allylcysteine (SAC), a water-soluble garlic derivative (1–100 mmol/L), inhibited the proliferation of human ovarian cancer cells A2780 cells in dose- and time-dependent manners (the IC_{50} value was approximately 25 mmol/L at 48 hours and less than 6.25 mmol/L at 96 hours) (Xu et al. 2014b). Treatment of A2780 cells with SAC resulted in G1/S phase arrest and induced apoptosis, accompanied by decreased expression of pro-caspase-3, Parp-1 and Bcl-2 and increased expression of active caspase-3 and Bax. S-benzylcysteine (SBC), a structural analogue of aged garlic S-allylcysteine (SAC), exerted cytotoxic activity involving activation of mitochondrial-dependent apoptosis through p53 and Bax/Bcl-2 pathways in human gastric cancer SGC-7901 cells (Sun et al. 2013). Studies showed that the proliferation rate and colony-forming abilities of hepatocellular carcinoma HCC metastatic MHCC97L cells were suppressed by S-allylcysteine (SAC), together with significant suppression of the expressions of proliferation markers, Ki-67 and proliferating cell nuclear antigen (PCNA) (Ng et al. 2012). Moreover, SAC hindered the migration and invasion of MHCC97L cells and significantly induced apoptosis and necrosis of MHCC97L cells. In-vivo xenograft liver tumour model demonstrated that SAC single or combined with cisplatin treatment inhibited the progression and metastasis of hepatocellular carcinoma tumour.

Animal Studies

Growth of Ehrlich ascites tumour-bearing mice was significantly inhibited by feeding garlic as well as some amino acids (Choy et al. 1983). These materials significantly reduced the total number of free tumour cells growing in the peritoneal cavity of mice and prolonged significantly the length of time for 50 % death of tumour-bearing mice. The tumour yield and incidence of phorbol-myristate-acetate promotion were inhibited in a dose-dependent manner over the range of 10–10,000 μg onion oil, applied three times per week (Belman 1983). Garlic oil was also inhibitory but was less effective. Gavage administration of diallyl sulfide, from garlic, to C57BL/6J mice inhibited by 74 % the incidence and reduced the frequency of colorectal adenocarcinoma induced by 20 weekly injections of 1,2-dimethylhydrazine (Wargovich 1987). Gavage administration of diallyl sulfide, from garlic, to C57BL/6J mice inhibited by 74 % the incidence and reduced the frequency of colorectal adenocarcinoma induced by 20 weekly injections of 1,2-dimethylhydrazine (Wargovich 1987). Gavage administration of diallyl sulfide, from garlic, to C57BL/6J mice inhibited by 74 % the incidence and reduced the frequency of colorectal adenocarcinoma induced by 20 weekly injections of 1,2-dimethylhydrazine (Wargovich 1987).

Topical application of garlic oil during the initiation phase of benzo[*a*]pyrene (B(a)P)-induced skin carcinogenesis in adult female Swiss albino mice caused a decline in the number of tumour-bearing mice as well as in the mean number of tumours per effective mouse (Sadhana et al. 1988). Garlic extract inhibited 7,12-dimethylbenz[a] anthracene (DMBA)-induced skin carcinogenesis in Swiss albino mice (Rao et al. 1990). Topical application of garlic extract twice daily for 3 days every week prior to DMBA administration at 200 nmol during the first week followed by 100 nmol during subsequent weeks reduced tumour incidence from 73.9 to 31.8 %. Similar garlic application prior to DMBA administration at 400 nmol during the first week followed by 200 nmol during subsequent weeks reduced tumour incidence from 100 to 43.45 %. Studies demonstrated that garlic powder was effective in inhibiting 7,12-dimethylbenz[a]anthracene (DMBA)-induced mammary tumours in rats, possibly by reducing DMBA–DNA binding

(Liu et al. 1992). Supplementation of garlic, selenium-enriched garlic and allyl group-containing sulfide constituents of garlic to the basal AIN-76A diet suppressed DMBA-induced mammary tumour in rats (Ip et al. 1992). Animals given the selenium-enriched garlic (final concentration 3 ppm Se in the diet) developed the fewest mammary tumours. They found a high intake of selenium-enriched garlic did not affect 5′-deiodinase activity in rats suggesting that its anticarcinogenic effect was unlikely to be mediated by an imbalance in the blood T4 to T3 ratio (Ip and Lisk 1993). Dietary fortification with S-allylcysteine (SAC), a water-soluble constituent of processed garlic, caused a progressive decrease in the binding of the carcinogen 7,12-dimethylbenz[a]anthracene (DMBA) to rat mammary cell DNA (Amagase and Milner 1993). The results suggested the primary effect of garlic and its constituents SAC was on the bioactivation and binding of the carcinogen rather than DNA repair.

Oral administration of garlic at the dose level of 400 mg/kg body wt./day for 2 weeks before and 4 weeks following 3-methylcholanthrene carcinogen thread insertion into the uterine cervix of virgin young adult Swiss albino mice significantly reduced the incidence of carcinoma to 23 % compared with 73 % in the positive control (Hussain et al. 1990). Co-administration of aged garlic extract (AGE) with naltrexone resulted in improvement of immune responses against experimentally implanted WEHI-164 fibrosarcoma tumours in BALB/c mice (Ebrahimpour et al. 2013). AGE showed synergistic effects with naltrexone on the inhibition of tumour growth and increment of survival times of mice.

Eight organosulfur compounds from garlic and onions allyl methyl trisulfide (AMT), allyl methyl disulfide (AMD), diallyl trisulfide (DAT) and diallyl sulfide (DAS) and also four corresponding saturated compounds in which propyl groups were substituted for the allyl groups were tested for their inhibitory effects on benzo[a] pyrene (BP)-induced neoplasia of the forestomach and lung of female A/J mice (Sparnins et al. 1988). DAS and AMD, but not DAT or AMT, inhibited pulmonary adenoma formation. All four allylic compounds induced increased glutathione S-transferase (GST) activity in the forestomach, but varied in their capacity to induce GST in the lung, liver and small bowel. Their saturated analogues produced little or no induction. Topical application of diallyl sulfide or diallyl disulfide significantly inhibited skin papilloma formation from the ninth week of promotion and significantly increased the rate of survival in mice (Dwivedi et al. 1992). Diallyl disulfide (DDS) exhibited inhibitory potential in the colon and renal carcinogenesis induced by the carcinogen N-diethylnitrosamine in rats (Takahashi et al. 1992). However, diallyl sulfide (DS) demonstrated clear enhancing effects on the development of glutathione S-transferase placental form-positive foci in rats and may promote hepatocarcinogenesis. Diallyl disulfide (DADS) treatment significantly inhibited the growth of H-ras oncogene-transformed tumours in nude mice (Singh et al. 1996b). The levels of membrane-associated p21H-ras were markedly lower in the tumour tissues of DADS-treated mice as compared to controls. An opposite trend, however, was evident for cytosolic p21H-ras. Further, DADS treatment resulted in a significant inhibition of hepatic as well as tumoral 3-hydroxy-3-methylglutaryl coenzyme A reductase activity. Treatment of mice with diallyl sulfide (DAS), diallyl disulfide (DADS) and diallyl trisulfide (DATS) prevented benzo(a)pyrene (BP)-induced cancer (Srivastava et al. 1997). Results suggested that while reduction of ethoxyresorufin O-deethylase (EROD) activity may, at least in part, contribute to the DAS-mediated inhibition of BP-induced lung cancer, anticarcinogenic effects of organosulfides against BP-induced forestomach carcinogenesis appeared to be independent of this mechanism. Treatment of mice with DAS, DADS and DATS resulted in a significant increase, as in hepatic and glutathione transferase (GST) activity towards anti-7β,8α-dihydroxy-9α,10α-oxy-7,8,9,10-tetrahydrobenzo(a)pyrene (anti-BPDE), the ultimate carcinogen of BP. The antitumour activity of DAS was of a much higher magnitude in benzo[a]pyrene (B(a)P)-induced carcinogenesis in comparison to mice exposed to 7,12-dimethylbenzanthracene (DMBA) in terms

of tumour incidence, cumulative number of tumours and average number of tumours per mouse (Singh and Shukla 1998). The results showed that DAS had a protective effect in the polycyclic aromatic hydrocarbon-induced mouse skin carcinogenesis. Oral gavage of DATS significantly retarded the growth of human prostate cancer PC-3 xenografts in athymic mice without causing weight loss (Xiao et al. 2006). The DATS-mediated suppression of PC-3 xenograft growth correlated with the induction of pro-apoptotic proteins Bax and Bak.

Oral administration of 5 μmol/kg diallyl trisulfide (DATS) to female BALB/c mice inhibited the growth of human MCF-7 cell tumour xenografts (Na et al. 2012). Diallyl trisulfide (DATS) showed the most potent antiproliferative effects in human breast cancer MCF-7 cells. MCF-7 cells treated with DATS underwent apoptotic death as revealed by a progressive increase in the proportion of the sub-G0/G1 cell population. In-vitro experiments indicated that DATS promoted gene expression of multidrug resistant 1 (Mdr1) and diallyl sulfide (DAS), and diallyl disulfide (DADS) promoted MRP3 gene expression, and DATS alone stimulated gene expression of multidrug resistance-associated protein 1 (MRP1) in colo 205 human colon cancer cells (Lai et al. 2012). In-vivo studies demonstrated that DADS and DATS induced Mdr1 and MRP1 gene expression. DADS promoted MRP3 gene expression as well as DADS, and DATS increased MRP4 and MRP6 gene expression in the colo 205 xenograft mice.

Garlic powder, water-soluble S-allylcysteine (SAC) and oil-soluble diallyl disulfide (DADS), supplementation significantly delayed the onset of mammary tumours induced by N-methyl-N-nitrosourea (MNU) and reduced the tumour incidence and total tumour number compared to rats receiving the unsupplemented diet (Schaffer et al. 1996). In a separate study the quantity of mammary DNA alkylation occurring 3 hours after MNU treatment was reduced in rats fed with garlic, SAC or DADS. Specifically, *O*(6)-methylguanine adducts and N(7)-methylguanine adducts were reduced, compared to controls. They also found that garlic powder and allyl sulfur compounds SAC and DADS enhanced the ability of dietary selenite to inhibit 7,12-dimethylbenz[a]anthracene-induced mammary DNA adducts (Schaffer et al. 1997). S-allylcysteine (SAC) at doses of 666 and 2,000 ppm did not exert an inhibitory effect on any index of mammary tumour development induced by N-methylnitrosourea in rats, including incidence, latency, multiplicity or volume, compared with untreated controls contradicting results of previous animal model studies (Cohen et al. 1999).

Animals that received 5 weekly immunisations of garlic (cumulative dose = 13 mg) had significantly reduced tumour incidence, tumour growth of MBT2 murine bladder carcinoma and increased survival when compared with mice that received the saline control (Riggs et al. 1997). No treatment-related deaths were observed with this treatment schedule. Further, mice that received 50 mg garlic orally had significant reductions in tumour volume when compared with animals that received the saline control, and mice that received 500 mg garlic orally had significant reductions in both tumour volume and mortality.

Studies showed that tomato and garlic suspensions had a protective effect on colon carcinogenesis induced by azoxymethane in rats (Sengupta et al. 2003). It was observed that aberrant crypt foci were reduced in all treated groups (by 32.11 % in garlic, by 76.14 % in tomato and by 55.96 % in the tomato–garlic combined group). Among treated groups, glutathione S-transferase (GST) activity was found to be induced in both the liver and colon, whereas considerable reduction in lipid peroxidation level was observed in the liver as well as in the colon with respect to the untreated azoxymethane control group. Significant reduction in Brdu labelling index and increase in apoptotic index in the colon were noted in the treated groups. The growth of transplanted human colon cancer cell line SW480 in the back of nude mice was inhibited markedly by DADS (diallyl disulfide); the relative tumour growth rate (T/C%) was 49.85 % (Liao et al. 2007). The protein level of proliferating cell nuclear antigen (PCNA) was significantly

lower in DADS group than in the control group. SW480 cells in DADS group were arrested in G2/M phase; the G2/M phase proportion was significantly higher in DADS group than in the control group. They found that DADS induced G(2)/M arrest in human colon cancer SW480 cells, probably through the downregulation of PCNA, p53 and cyclin B1 and upregulation of p21(WAF1) (Liao et al. 2009). Dose-dependent apoptosis was detected in aged black garlic extracts (ABGE)-treated gastric cancer cells in in-vitro studies (Wang et al. 2012b). In foregastric cancer tumour-bearing Kunming mice, significant antitumour effects of ABGE were observed, such as growth inhibition of inoculated tumours. Further investigation of serum superoxide dismutases, glutathione peroxidase, interleukin 2 and the increased indices of spleen and thymus indicated that the anticancer action of ABGE may be partly due to its antioxidant and immunomodulative effects.

Garlic extract was proven to be effective in inhibiting initial events caused by 12-*O*-tetradecanoyl-phorbol-13-acetate (TPA), type tumour promoters in-vitro and in-vivo (Nishino et al. 1989). The first stage of tumour promotion in two-stage mouse skin carcinogenesis in-vivo was suppressed by the treatment with garlic extract. Garlic oil was also inhibitory but was less effective. Garlic and onion oil treatments inhibited dramatically the sharp decline in the intracellular ratio of reduced glutathione (GSH)/oxidised (GSSG) glutathione caused by tumour promoter 12-0-tetradecanoylphorbol-13-acetate (TPA); thus, it was suggested that some of the inhibitory effects of garlic and onion oils on skin tumour promotion may result from their enhancement of the natural GSH-dependent antioxidant protective system of the epidermal cells (Perchellet et al. 1986). Garlic oil (5 μg/mL) inhibited by about 50 % TPA-induced ornithine decarboxylase (ODC, L-ornithine carboxy-lyase) activity in the same epidermal cell system. Application of garlic oil inhibited skin tumorigenesis in Sencar mouse initiated by 7,12-dimethylbenz[a]-anthracene (DMBA) and also inhibited two tumour promotion stages by TPA in DMBA initiated SENCAR mice (Perchellet et al. 1990). The number of papillomas per mouse was significantly reduced by garlic oil but not by propenyl sulfide. DAS treatment caused a significant increase in glutathione S-transferase (GST) activity, an enzyme system responsible for the detoxification of a variety of electrophilic xenobiotics including several harmful benzo[a]pyrene (B[a]P) metabolites of mouse stomach in a dose-dependent manner (Gudi and Singh 1991). DAS treatment also resulted in increased pulmonary GST activity, but not in a dose-dependent fashion. Treatment of animals with DAS increased stomach glutathione (GSH) peroxidase activity. In contrast, GSH peroxidase activity in the liver and kidney was unchanged by DAS treatment. The results suggested that DAS and perhaps other naturally occurring organosulfur compounds may exert an antineoplastic effect by modulating GSH-dependent detoxification enzymes. The inhibition by garlic oil was most effective when given one hour before TPA but was evident when given from two hours before to two hours after TPA. Ajoene, oil-macerated garlic products, inhibited in a two-stage carcinogenesis test on mouse skin (Nishikawa et al. 2002). Treatment with ajoene suppressed skin tumour formation. Mice treated with 250 μg of ajoene had only 4.9 % the number of tumours per mouse compared with the control group at 18 weeks. Tamoxifen (TAM) combination with allicin (5 or 10 μM) showed a significant cytotoxic effect compared with the TAM-treated group as manifested by a decrease in the percent survival of Ehrlich ascites carcinoma to 35 % and 29 %, respectively (Suddek 2014). Allicin (10 mg/kg, orally) enhanced the efficacy of TAM (1 mg/kg, i.p.) in mice as manifested by a significant increase in solid tumour growth inhibition by 82 % compared with 70 % in the TAM group. In rats, TAM intoxication resulted in a significant decline in SOD, GSH and total protein with significant elevation in TBARS, ALT and AST, ALP, LDH, total bilirubin, γGT and TNF-α levels. These changes were abrogated by allicin treatment. The results suggested the beneficial role of allicin as an adjuvant to TAM in cancer treatment by alleviating liver injury.

Thiacremonone (0–50 μg/mL), generated from high-temperature high-pressure-treated garlic, inhibited human lung cancer cell, A549 and NCI-H460, growth in a concentration-dependent manner through induction of apoptotic cell death accompanied by induction of cleaved caspase-3, caspase-8, caspase-9, Bax, p21 and p53, but decrease of xIAP, cIAP and Bcl-2 expression (Jo et al. 2014). Thiacremonone further inhibited glutathione peroxidase activity in lung cancer cells. In an allograft in-vivo model, thiacremonone (30 mg/kg) also inhibited lung cancer cell, A549 and NCI-H460, tumour growth accompanied with the reduction of peroxiredoxin 6 (PRDX6) expression and glutathione peroxidase activity, but increased expression of cleaved caspase-3, caspase-8, caspase-9, Bax, p21 and p53. The data indicated that thiacremonone inhibited tumour growth via inhibition of glutathione peroxidase activity of PRDX6 through interaction.

Clinical Studies

Tilli et al. (2003) applied ajoene topically to the tumours of 21 patients with either nodular or superficial basal cell carcinoma (BCC). A reduction in tumour size was seen in 17 patients. The BCC cell line TE354T and a short-term primary culture of BCC were analysed for apoptosis induction after treatment with the drug. Apoptosis was detected by morphology of the cells and by flow cytometry. Ajoene induced apoptosis in a dose- and time-dependent manner in these cultures.

Epidemiological/Meta-analytical/Review Studies

Omar and Al-Wabel (2010) reported that research evidence supported the protective effects of garlic in stomach, colorectal and breast cancer in humans. The protective effects appeared to be related to the presence of organosulfur compounds, predominantly allyl derivatives, which also had been shown to inhibit carcinogenesis in the forestomach, oesophagus, colon, mammary gland and lung of experimental animals. Several mechanisms had been proposed for the cancer-preventive effects, modulation of several metabolising enzymes that activated (cytochrome P450s) or detoxified (glutathione *S*-transferases) carcinogens, and inhibited the formation of DNA adducts in several target tissues and antiproliferative activity possibly mediated by the induction of apoptosis and alterations of the cell cycle.

It was found that the inhabitants in Cangshan County, Shandong Province, usually take fresh garlic as daily food, and the mortality from gastric cancer for the inhabitants in Cangshan was found to be significantly lower than that in Qixia County where the inhabitants rarely take garlic (Xing et al. 1982). It was also found that the nitrite concentration in gastric juice of the inhabitants in Cangshan was significantly lower than that in Qixia. The reduction rate (%) of nitrite concentration in gastric juice after the introduction of 10 g of fresh garlic in the form of homogenate was significantly larger than that of the control test in tested persons at Shandong Medical Research Institute. It was proven that garlic promoted the inhibition of nitrate-reducing bacteria and reduction of nitrite formation and be considered as a protective factor against the carcinogenesis of gastric cancer.

The Netherlands Cohort Study which started in 1986 with 120,852 men and women ranging in age from 55 to 69 years provided evidence for a strong inverse association between onion consumption and stomach carcinoma incidence (Dorant et al. 1996b). The consumption of leeks and the use of garlic supplements were not associated with stomach carcinoma risk. Also, the Netherlands Cohort Study did not support an inverse association between the consumption of onions and leeks or the use of garlic supplements and the incidence of male and female colon and rectum carcinoma (Dorant et al. 1996a). Also, the Netherlands Cohort Study found that garlic supplement use was not associated with breast carcinoma incidence (rate ratio = 0.87) (Dorant et al. 1995) and lung carcinoma (Dorant et al. 1994). In a case-control study of 345 patients diagnosed with primary breast carcinoma between 1986 and 1989 conducted in France, Challier et al. (1998) found that accounting for total caloric intake and established risk factors breast cancer risk was shown to decrease as consumption of fibre, garlic and onions increased. This study also supported

the epidemiologic evidence that saturated fat intake and breast cancer risk are associated in postmenopausal women and conversely that unsaturated fat intake could lower the risk in the same subgroup. In a case-referent study conducted in Jiangsu province, China, on histopathologically confirmed cases for oesophageal cancer ($n=81$) and stomach cancer ($n=153$) and population-based referents ($n=234$), frequent intake of *Allium* vegetables (garlic, onion, Welsh onion and Chinese chives) was found to be inversely associated with the risk for both cancers (Gao et al. 1999). In the highest consumption category (>or =1 time/week) of garlic, onion, Welsh onion and Chinese chives, the adjusted odd ratios compared with the lowest category (<1 time/month) were 0.30 (CI=0.19–0.47), 0.25 (CI=0.11–0.54), 0.15 (CI=0.08–0.26) and 0.57 (CI=0.23–1.42) for oesophageal cancer and 0.31 (CI=0.22–0.44), 0.17 (CI=0.08–0.36), 0.22 (CI=0.15–0.31) and 0.40 (CI=0.17–0.94) for stomach cancer, respectively. In an interview study of 564 patients with stomach cancer and 1,131 controls in an area of China with high rates of gastric cancer, a significant reduction in gastric cancer risk with increasing consumption of garlic, onions and other *Allium* vegetables (You et al. 1989). Persons in the highest quartile of intake experienced only 40 % of the risk of those in the lowest. Protective effects were seen for *Allium* foods. The meta-analysis conducted by Fleischauer et al. (2000) found that high intake of raw garlic or cooked garlic may be associated with a protective effect against stomach and colorectal cancers. Heterogeneity of effect estimates, differences in dose estimation, publication bias and possible alternative hypotheses (e.g. confounding by total vegetable consumption) precluded sole reliance on summary effect estimates. Results of a double-blind intervention study carried out in China, involving 2,526 people (35–74 years old) in the intervention group and 2,507 in the control group, showed that large doses of allitridum and micro-dose of selenium for a year may effectively prevent gastric cancer in the male population (Li et al. 2004).

Analysis of large data from an integrated network of Italian and Swiss case-control studies showed an inverse association between the frequency of use of onion and garlic and the risk of several common cancers (Galeone et al. 2006). The multivariate odd ratios for the highest category of onion and garlic intake were, respectively, 0.16 and 0.61 for cancer of the oral cavity and pharynx, 0.12 and 0.43 for oesophageal cancer, 0.44 and 0.74 for colorectal cancer, 0.17 and 0.56 for laryngeal cancer, 0.75 and 0.90 for breast cancer, 0.27 and 0.78 for ovarian cancer, 0.29 and 0.81 for prostate cancer and 0.62 and 0.69 for renal cell cancer. A large multi-centre case-control study of 1,369 patients with benign prostatic hyperplasia and 1,451 controls in Italy showed an inverse association between onion and garlic consumption and benign prostatic hyperplasia (Galeone et al. 2007). The inverse relationships were consistent across age strata. In a multi-centre case-control study of 454 endometrial cancer cases and 908 controls, Galeone et al. (2009) found a moderate protective role of onion and garlic on the risk of endometrial cancer. Compared with nonusers, the odd ratios of endometrial cancer for successive categories of onion intake were 0.94 for <2 portions/week and 0.40 for > or =2 portions/week, with a significant inverse trend in risk. The odd ratio for an increment of one portion (i.e. 80 g) of onions per week was 0.81. For garlic, the odd ratios for successive categories of intake were 0.89 for intermediate use and 0.62 for high use, with a significant inverse trend in risk.

In a large population-based case-control study in Shanghai (750 cases and 750 age- and gender-matched controls) and Qingdao (201 cases and 201 age- and gender-matched controls), Setiawan et al. (2005) found inverse relationships with dose-response pattern were observed between frequency of onion intake and stomach cancer in Qingdao and Shanghai after adjusting for matching variables, education, body mass index, pack-years of smoking, alcohol drinking, salt intake and fruit and vegetable intake. In Shanghai, negative dose-response relationships were observed between monthly intake of onions or garlic stalks and distal, but not cardiac cancer. A negative association was also noted between intake of garlic stalks (often vs. never) and risk of stomach

cancer in Qingdao (odds ratio = 0.30). Their results confirmed protective effects of *Allium* vegetables (especially garlic and onions) against stomach cancer. In a meta-analysis, consumption of high levels of *Allium* vegetables (onion, garlic, leek, Chinese chive, scallion, garlic stalk and Welsh onion) reduced the risk for gastric cancer risk (odds ratio = 0.54) (Zhou et al. 2011). Specific analyses for onion, garlic, leek, Chinese chive, scallion, garlic stalk and Welsh onion yielded similar results, except for onion leaf. In a population-based case-control study conducted in a Chinese population from 2003 to 2010, after adjusting for potential confounding factors, raw garlic consumption of two times or more per week was found to be inversely associated with lung cancer (odds ratio (OR) = 0.56) with a monotonic dose-response relationship (Jin et al. 2013).

In the meta-analysis of 8 studies with 20 reports of the effects of *Allium* vegetables (5,458 patients with colorectal cancer including 7,125,067 person-years) and 5 studies with 11 reports of the effects of garlic supplements (2,685 patients with colorectal cancer including 2,304,439 person-years), Zhu et al. (2014) found no evidence that higher intake of *Allium* vegetables reduced the risk for colorectal cancer. They observed that garlic supplements increased the risk for colorectal cancer.

Antimutagenic/Anticlastogenic Activity

Aqueous garlic bulb extract markedly suppressed the mutagenesis in both *Escherichia coli* WP2 trp− and *E. coli* WP2 trp− uvrA− induced by 4-nitroquinoline l-oxide (4NQO), but not that induced by UV (Zhang et al. 1989). It was suggested that the extract might act by inactivating the electrophilic group(s) of 4NQO or inhibiting its metabolic activation. Experiments with *Salmonella* tester strains indicated that aqueous garlic extract possessed antimutagenic properties towards ionising radiation, peroxides, adriamycin and N-methyl-N′-nitro-nitrosoguanidine (Knasmüller et al. 1989). Radical scavenging garlic constituents, i.e. molecules with sulfur moieties, were confirmed to be responsible for the inhibitory effect of aqueous extract towards mutagenesis induced by radiation and radiomimetic compounds. Garlic extract attenuated the lethal effects of gamma rays on repair-deficient *Escherichia coli* strains; the garlic constituent allicin (thio-2-propene-1-sulfinic acid S-allyl ester) was partly responsible for the reduced radiation-induced mutagenesis in *Salmonella typhimurium* TA 102. No such inhibitory effects were detected with alliin (S-allyl-L-cysteine sulfoxide) or cysteine; aqueous garlic extract inhibited hydrogen peroxide-induced lipid peroxidation. Results obtained in preliminary experiments with Chinese hamster ovary cells suggested that the antimutagenic properties of garlic extract were not restricted to procaryotic cells.

Oral or parenteral pretreatment with DAS significantly and dose dependently inhibited N-methyl-N′-nitro-N-nitrosoguanidine (MNNG)-induced nuclear aberration and ornithine decarboxylase activity in Wistar rat glandular stomach mucosa (Hu and Wargovich 1989; Hu 1990). The suppressions were observed to be dose dependent. The data supported the epidemiologic evidence of the chemopreventive effect of garlic on gastric cancer.

Allixin, a phytoalexin isolated from garlic, dose dependently inhibited histidine+ revertants induced by aflatoxin B1(AFB1) in *Salmonella typhimurium* TA100 (Yamasaki et al. 1991). Allixin at 75 μg/mL inhibited [3H]AFB1 binding to calf thymus DNA and reduced formation of AFB1-DNA adducts. In addition, allixin exhibited a concentration-dependent inhibition of the formation of organosoluble metabolites and the glutathione conjugates of [3H]AFB1. The data indicated that the effect of allixin on AFB1-induced mutagenesis and binding of metabolites to DNA may be mediated through an inhibition of microsomal P450 enzymes. Crude garlic extract, ajoene and diallyl sulfide (DAS) inhibited rat liver 9,000 g supernatant (S-9) mutagenesis induced by aflatoxin B1 (AFB1) (Tadi et al. 1991b). They also inhibited AFB1 binding to DNA. Dietary administration of turmeric (0.05 %), garlic (0.25 %), curcumin and ellagic

acid (0.005 % each) to rats significantly reduced the number of γ-glutamyl transpeptidase-positive foci induced by aflatoxin B1, the precursor of hepatocellular neoplasm (Soni et al. 1997). The results indicated the usefulness of antioxidant food additives in ameliorating aflatoxin-induced mutagenicity and carcinogenicity. Studies demonstrated that while dietary garlic could reduce DNA adduct formation in mammary tissue caused by 7,12-dimethylbenz(a)anthracene (DMBA) in rats, this protection was influenced by several dietary components (Amagase et al. 1996). Garlic supplementation prevented the increase in DNA adducts caused by increasing dietary corn oil. Combining dietary supplements of garlic, selenite (0.5 mg/kg diet) and retinyl acetate (328 mg/kg diet) inhibited the occurrence of DNA adducts to a greater degree than when each was supplied individually.

The clastogenicity of three mutagens, clastogens, mitomycin C(1.5 mg/kg) and cyclophosphamide (25 mg/kg) or sodium arsenite (2.5 mg/kg), were reduced significantly in mice which had been given garlic extract as a dietary supplement (Das et al. 1993). Addition of 2 % garlic powder to diets containing aminopyrine and sodium nitrite (each at 600 mg/kg) reduced the occurrence of both 7-N-methyldeoxyguanosine (7-N-mG) and 6-*O*-methyldeoxyguanosine (6-O-mG) adducts to rat liver DNA by approximately 55 % and over 80 % when 4 % garlic was provided (Lin et al. 1994). Dietary supplementation with garlic powder (2 and 4 %) also reduced the occurrence of 7-N-mG and 6-*O*-mG adducts by approximately 40 and 60 %, respectively, in rats intubated with N-nitrosodimethylamine (150 mg/kg body wt). The quantity of 7-N-mG and 6-O-mG adducts in mammary tissue of rats given intravenous N-methyl-N-nitrosourea (50 mg/kg body wt) was reduced over 50 % in rats fed with 2 % garlic compared to controls. Raw garlic aqueous extract significantly inhibited benzo[a]pyrene (BaP)–DNA adduct formation at concentrations of 0.001, 0.01 and 0.1 mg/mL (Hageman et al. 1997). S-allylcysteine (SAC) also significantly decreased BaP–DNA adduct formation at concentrations of 0.01 and 0.1 mg/mL. For diallyl sulfide, no significant reduction in BaP–DNA adduct formation was found. In addition, reactive oxygen species-induced 8-oxodeoxyguanosine in DNA was reduced in the presence of SAC.

Feeding house mouse, *Mus musculus*, with aqueous garlic extract or mustard oil separately or simultaneously prior to several subcutaneous injection of the clastogen, sodium arsenite, attenuated the clastogenic activity of sodium arsenite (Choudhury et al. 1997a). The degree of modulation of sodium arsenite-induced chromosomal aberrations was more pronounced in mustard oil than in garlic extract, and simultaneous administration of both the dietary supplements reduced the clastogenic effects of sodium arsenite closer to the level of the negative control. The greater efficacy could be due to the interaction of the two dietary supplements and its radical scavenging property.

Water extracts of garlic, deodorised garlic powder and onions, but not leeks, were found to reduce the in-vitro formation of N-nitrosomorpholine (NMOR), a known liver carcinogen (Dion et al. 1997). Addition of increasing quantities (20, 40 and 80 mM) of S-allylcysteine (SAC), a water-soluble compound in processed garlic, depressed NMOR formation by 16 %, 27 % and 43 %, respectively. SAC and S-propyl cysteine were less effective than isomolar cysteine in reducing NMOR formation. The oil-soluble sulfur compounds diallyl disulfide (DADS), dipropyl disulfide and diallyl sulfide were ineffective inhibitors of NMOR generation. SAC and DADS reduced the mutagenicity of NMOR in *Salmonella typhimurium* TA100. SAC at 70 μmol/plate reduced the number of histidine revertants per plate by 51 %, whereas DADS at 0.12 μmol/plate reduced mutant colony number by 76 %. SAC and DADS were more effective than isomolar cysteine in reducing NMOR mutagenicity. Garlic extract exhibited antigenotoxic and protective effects against vinblastine in human lymphocyte cultures in-vitro (Sinduja et al. 2012). Garlic caused a significant decrease in the frequency of chromosome aberration suggesting that the garlic extract modulated the vinblastine-induced cytotoxicity in a dose-dependent manner.

Feeding rats with dried garlic powder at 0.1, 0.5 and 1 % concentrations for 4 weeks prior to

intraperitoneal challenge with the carcinogen benzo[*a*]pyrene (1 mg/rat) caused a significant reduction in the excretion of urinary mutagens (Polasa and Krishnaswamy 1997). Further, there was stimulation in the activities of liver cytosolic glutathione S-transferase and liver and lung quinone reductases. The results suggested that the antimutagenic potential of garlic may be mediated through the induction of detoxification enzymes in target tissues.

Daily gavage administration of three concentrations (25, 50 and 100 mg/kg body weight) of fresh garlic to Swiss albino mice for different durations up to 60 days was observed to protect significantly against effects of known clastogens (Das et al. 1996). Frequencies of chromosomal aberrations and damaged cells induced in bone marrow preparations were found to be directly dose dependent and after an initial enhancement at 7 days were reduced following prolonged exposure for 30 and 60 days to the low level observed at 24 hours. Thus, administration of a low concentration of garlic extract daily was suggested for at least 30 days to obtain the maximum benefit of the extract in protecting against the clastogenic effects of known genotoxicants. The clastogenic affects of prolonged exposure to sodium arsenite, a strong clastogen, was reduced by a highly significant amount when crude garlic extract (equivalent to 6 g for 60 kg human body) was given daily to the mice by intubation for the same period (Choudhury et al. 1997b). Feeding house mouse, *Mus musculus*, with aqueous garlic extract or mustard oil separately or simultaneously prior to several subcutaneous injection of the clastogen, sodium arsenite, attenuated the clastogenic activity of sodium arsenite (Choudhury et al. 1997a). The degree of modulation of sodium arsenite-induced chromosomal aberrations was more pronounced in mustard oil than in garlic extract, and simultaneous administration of both the dietary supplements reduced the clastogenic effects of sodium arsenite closer to the level of the negative control. The greater efficacy could be due to the interaction of the two dietary supplements and its radical scavenging property.

In a study of human volunteers, consumption of whole strawberries, garlic juice or kale juice immediately after an amine-rich diet with a nitrate was found to reduce endogenous N-nitrosodimethylamine (NDMA, a carcinogen) formation (Chung et al. 2002). NDMA excretion was decreased by 70, 71 and 44 %, respectively, compared with NDMA excretion after ingestion of an amine-rich diet with a nitrate. Strawberry, garlic and kale extracts inhibited nitrosation in-vitro.

Antifungal Activity

The mycelial phase of *Histoplasma capsulatum* was inhibited by both the volatile and water-soluble components of garlic (Fliermans 1973). Garlic extract at a concentration of 254 ppb was inhibitory, while 8.1 ppm was lethal to pure cultures of *H. capsulatum*. Garlic fractions A, B, allicin and ajoene exhibited antifungal activity in-vitro (Yoshida et al. 1987). Ajoene inhibited the growth of *Paracoccidioides brasiliensis*, a fungal pathogen for humans, by affecting the integrity of the fungal cytoplasmic membrane (San-Blas et al. 1989). Ajoene inhibited the growth of the dimorphic pathogenic fungus *Paracoccidioides brasiliensis*, yeast cells being more sensitive to its action than mycelial cultures (San-Blas et al. 1993). Low concentrations of aqueous garlic extract were both inhibitory and lethal to numerous strains of *Cryptococcus neoformans* (Fromtling and Bulmer 1978). Intravenous administration of commercial garlic extract to two patients with cryptococcal meningitis and three patients with other types of meningitis-augmented plasma titres of anti-*Cryptococcus neoformans* activity rose twofold over preinfusion titres (Davis et al. 1990). Anti-*Cryptococcus neoformans* activity was detected in four of five cerebrospinal fluid samples but not in pooled normal cerebrospinal fluid. Ajoene exhibited the most potent inhibitory activity against the growth of both *Aspergillus niger* and *Candida albicans* at less than 20 μg/mL (Yoshida et al. 1987). Allicin was effective in-vitro against *Candida*, *Cryptococcus*, *Trichophyton mentagrophytes*, *Epidermophyton floccosum* and *Microsporum gypseum* (Yamada and Azuma 1977). The minimal inhibitory concentrations (MICs) of allicin

against these organisms were 3.13–6.25 μg/mL by the agar dilution method and 1.57–6.25 μg/mL by the broth dilution method, using Sabouraud glucose (SG) medium. The MIC value against *Aspergillus fumigatus* was 12.5–25 μg/mL in both agar dilution and broth after 5 days and against *Cryptococcus neoformans* and *Candida albicans* on both media after 5 days were 3.23 and 6.25 μg/mL, respectively. Garlic extract administered orally appeared to reduce brain cryptococcal populations in mice, although the results obtained were generally inconsistent (Louria et al. 1989).

Aqueous garlic extract inhibited the growth of *Microsporum gypseum*, *Trichophyton verrucosum*, *Trichophyton violaceum*, *Trichophyton rubrum*, *Trichophyton schoenleini*, *Trichophyton mentagrophytes* and *Epidermophyton floccosum* in-vitro (Amer et al. 1980). Experimental dermatophyte infection was induced in guinea pigs and rabbits, and topical application or injection of garlic extract was very effective, producing complete healing in 14–17 days following twice daily application of the extract for 1 week (Amer et al. 1980). Among the *Allium* plants exhibiting antifungal activity, garlic extract showed the lowest minimal fungicidal concentration *against Aspergillus niger*, *A. flavus* and *A. fumigatus* (Yin and Tsao 1999). Acetic acid treatments of the extracts increased the inhibitory effect for all plants against three fungi.

Volatile components of crude aqueous extracts of garlic bulbs inhibited germination of microconidia and hyphal extension in *Fusarium oxysporum* f. sp. *lycopersici* in axenic culture (Tariq and Magee 1990). Garlic volatiles also inhibited the production of microconidia and chlamydospores. Extracts of turmeric (*Curcuma longa*), garlic (*Allium sativum*) and asafoetida (*Ferula asafoetida*) inhibited *Aspergillus parasiticus* aflatoxin production considerably (more than 90 %) at concentrations of 5–10 mg/mL (Soni et al. 1992). Allicin, one of the active principles of freshly crushed garlic homogenates, was found to exhibit (1) antibacterial activity against a wide range of Gram-negative and Gram-positive bacteria, including multidrug-resistant enterotoxicogenic strains of *Escherichia coli*; (2) antifungal activity, particularly against *Candida albicans*; (3) antiparasitic activity, including some major human intestinal protozoan parasites such as *Entamoeba histolytica* and *Giardia lamblia*; and (4) antiviral activity (Ankri and Mirelman 1999). The main antimicrobial effect of allicin was attributed to its chemical reaction with thiol groups of various enzymes, e.g. alcohol dehydrogenase, thioredoxin reductase and RNA polymerase, which could affect the essential metabolism of cysteine proteinase activity involved in the virulence of *E. histolytica*. The protein alliumin, isolated from garlic bulb, demonstrated antifungal activity against *Mycosphaerella arachidicola*, but not against *Fusarium oxysporum* (Xia and Ng 2005).

Yeast-like fungi representing the genera *Candida*, *Cryptococcus*, *Rhodotorula*, *Torulopsis* and *Trichosporon* were inhibited in-vitro in the presence of an aqueous extract of garlic (Moore and Atkins 1977). Fungi associated with vaginitis were inhibited and killed by an aqueous garlic extracted and diluted to 1:1,024 when incubated at 37 °C. Antimycotic activity was greater at 37 than at 30 °C. Twenty-two *C. albicans* isolates from active vaginitis cases were all inhibited by the garlic extract. Aqueous extracts of garlic bulbs were fungicidal for 39 of 41 clinical isolates of *Candida albicans* at 68 μg total dry weight of crude extract per ml of 2 % (w/v) malt extract broth in standing culture; the remaining two isolates gave variable or moderate growth at 68 μg/mL (Barone and Tansey 1977). In shake culture, the crude extract was fungistatic between 50 and 300 μg/mL and fungicidal above 400 μg/mL. Gradual loss of anticandidal activity occurred when crude extract was stored at 37 °C before being assayed; loss of activity was proportional to duration of heat treatment. Activity was stable in acid and unstable in base. Results suggested allicin to be the major anticandidal component and that other thiosulfinates in garlic extracts may have some anticandidal activity. Adetumbi et al. (1986) found that aqueous garlic extract completely inhibited lipid synthesis in *C. albicans*. Protein and nucleic acid syntheses were inhibited to the same extent as growth. Ghannoum (1988) found that the growth of *C. albicans* in the presence of aqueous garlic extract affected the yeast lipid in a number of ways: the total lipid content was decreased; garlic-grown yeasts had a

higher level of phosphatidylserines and a lower level of phosphatidylcholines; in addition to free sterols and sterol esters, *C. albicans* accumulated esterified steryl glycosides; the concentration of palmitic acid (16:0) and oleic acid (18:1) increased and that of linoleic acid (18:2) and linolenic acid (18:3) decreased. Oxygen consumption of garlic-treated *C. albicans* was also reduced. The anticandidal activity of garlic was antagonised by thiols such as L-cysteine, glutathione and 2-mercaptoethanol. The data suggested that garlic exerted its anticandidal effect by the oxidation of thiol groups present in the essential proteins, causing inactivation of enzymes and subsequent microbial growth inhibition. Adhesion of *Candida* spp. to buccal epithelial cells was significantly reduced after both short and long time exposure to aqueous garlic extract (Ghannoum 1988). There was a significant reduction in the adherence of *Candida* spp. to buccal epithelial cells collected immediately or 15 minutes after an oral rinse with garlic extract. Garlic aqueous extract inhibited the growth in-vitro of *Malassezia furfur* (25 strains), *Candida albicans* (18 strains), other *Candida* sp. (12 strains) as well as 35 strains of various dermatophyte species tested in a dose-dependent manner with maximum of 100 % at defined concentrations (Shams-Ghahfarokhi et al. 2006). In-vitro studies found that MIC_{50} and MIC_{90} values of allicin alone against six *Candida* spp. ranged from 0.05 to 25 μg/mL (Khodavandi et al. 2010). However, when allicin was used in combination with fluconazole or ketoconazole, the MICs were decreased in some isolates. The synergistic effect between allicin and azoles was demonstrated in some of the *Candida* spp. such *as C. albicans*, *C. glabrata* and *C. tropicalis* but not in *C. rugosa*, *C. parapsilosis* and *C. krusei*. Allicin was shown to enhance significantly the effect of amphotericin B against *Candida albicans* in-vitro and in-vivo, although allicin did not exert a fungicidal effect (An et al. 2009). Further study demonstrated that allicin-mediated oxidative damage, such as phospholipid peroxidation in the plasma membrane, via influencing the defence of *C. albicans* against oxidative damage may underpin the synergistic interaction between allicin and amphotericin B. Allicin was found to enhance amphotericin B-induced structural damage to fungal vacuolar membrane even at a non-lethal dose of the antibiotic (Ogita et al. 2006b). Allicin could also enhance the antifungal activity of AmB against the pathogenic fungus *Candida albicans* and against *Aspergillus fumigatus*. Allicin was not lethal but could markedly amplify the fungicidal activity of polymyxin B which was weakly detected with the increase in the plasma membrane permeability in *Saccharomyces cerevisiae* (Ogita et al. 2007). Their combined actions caused a dynamic structural damage to the yeast vacuole as judged by the disappearance of its swollen spherical architecture. The vacuole-targeting activity of PMB was similarly amplified in medium with t-butyl hydroperoxide as a substitute for the action of allicin. In-vitro studies suggested that the synergistic fungicidal action of Cu^{2+} and allicin from garlic was dependent on the selective accumulation of the ion in the plasma membrane fraction by allicin-enhanced cellular permeability and allicin-mediated phospholipid peroxidation (Ogita et al. 2006a). *Candida albicans* and *Candida tropicalis* cells treated with sublethal concentrations of diallyl disulfide (DADS) sustained a decrease in the activity of all antioxidant enzymes except catalase, resulting in oxidative stress and damaged cells (Yousuf et al. 2010). Increased levels of lipid peroxidation and decreased levels of glutathione were observed in DADS treated cells. Activity of glucose-6-phosphate dehydrogenase decreased significantly following DADS treatment and could be correlated with a decrease in glutathione concentration in both *Candida* species. The results indicated that diallyl disulfide acted as a pro-oxidant to *Candida* species and hence may act as a potent antifungal in the management of candidiasis.

Six different mixtures of garlic distilled oils containing diallyl disulfide (DDS) and diallyl trisulfide (DTS), ranging from 1 to 51 % and 88 to 38 %, respectively, exhibited antimicrobial activity against a number of yeasts (*Candida albicans*, *Candida tropicalis* and *Blastoschizomyces capitatus*), Gram-positive bacteria (*Staphylococcus aureus* and *Bacillus subtilis*) and Gram-negative bacteria (*Pseudomonas aeruginosa* and

Escherichia coli) (Avato et al. 2000). Incubation of garlic extracts made up of 1 % DDS and 88 % DTS resulted, in fact, in the absence of growth inhibition against all the tested microorganisms, whereas garlic oils with higher quantities of DDS showed significant inhibitory activity, increasing with the increase of DDS amount.

Fresh garlic extract had a greater efficacy than freeze-dried garlic powder extract as indicated both by its effects on morphology and inhibition of growth of *C. albicans* (Lemar et al. 2002). Both the growth and respiration of *Candida albicans* were sensitive to garlic extracts and to allyl alcohol, a metabolic trituration product of garlic (Lemar et al. 2005). Changes typical of oxidative stress, NADH oxidation and glutathione depletion and increased reactive oxygen species were observed in the treated yeast. Known targets for allyl alcohol were alcohol dehydrogenases Adh1 and Adh2 (in the cytosol) and Adh3 (mitochondrial), although the significant decrease in NAD(P)H after addition of allyl alcohol was indicative of another mechanism of action. Fresh garlic extract demonstrated inhibitory activity against *C. albicans* GDH 2,346, a strain isolated from a denture stomatitis patient, in its planktonic, adherent and sessile phases (Shuford et al. 2005). MICs for planktonic yeast were 0.0625–0.125 mg/mL. The in-vitro activity decreases as the biofilm phenotype developed, as noted previously with traditional antifungal drugs. The superior activity at 1 hour versus 48 hours of treatment is probably related to the half-life of garlic extract at 37 °C and would be an important consideration in the development of in-vivo uses. Garlic and its bioactive components displayed ability to suppress hyphae production and to affect the expression level of SIR2 gene in *C. albicans* (Low et al. 2008). Eruboside-B obtained by enzymatic hydrolysis of the furostanol glycoside proto-eruboside-B from garlic bulb inhibited the growth of *Candida albicans* in-vitro (25 µg/mL MIC) (Matsuura et al. 1988). The MICs of garlic extract for the yeasts were 1.4 mg/mL for *Candida albicans* and 1.9 mg/mL for *Saccharomyces cerevisiae* (Rees et al. 1993). Garlic also inhibited *Fusarium laceratum*, *Trichoderma hamatum*, *Aspergillus fumigatus* and *Geotrichum candidum* at the lowest concentration of 2 mg/mL. At this concentration, *Aspergillus fumigatus* was the most sensitive and *Geotrichum candidum* the least sensitive, although still showing 25 % after 8 days incubation. Antifungal N-feruloyl amides *N*-feruloyltyrosine and *N*-feruloyltyramine were isolated from *A. sativum* roots (Fattorusso et al. 1999). Both compounds resulted to be active against the pathogen *Fusarium culmorum* with ED_{50} of 20 and 22 µg/mL, respectively. The ethanolic garlic extract exhibited moderate inhibitory activity against the two isolates each of *Rhizopus stolonifer* (50 %), *Mucor* sp. (40 %), *Aspergillus luchuensis* (30 %), *Aspergillus flavus* (30 %) and *Scopulariopsis* sp. (20 %) but lacked in inhibitory activity against *Penicillium oxalicum* (Pundir et al. 2010).

A concentrated *A. sativum* extract containing 34 % allicin, 44 % total thiosulfinates and 20 % vinyldithiins exhibited potent in-vitro fungistatic and fungicidal activity against 3 different isolates of *Cryptococcus neoformans* (Davis et al. 1994). The minimum inhibitory concentration (MIC) of the concentrated garlic extract against 1×10^5 organisms of *C. neoformans* ranged from 6 to 12 µg/mL. In addition, in-vitro synergistic fungistatic activity with amphotericin B was demonstrated against all isolates of *C. neoformans*. Of 21 plant extracts tested, only the aqueous extract of garlic exhibited potent in-vitro activity against *Trichophyton rubrum* human skin pathogen (Samuel et al. 2000). However, the antifungal activity was lost when the extract was heated above 60 °C. Garlic and onion essential oils and their constituent diallyl trisulfide, diallyl tetrasulfide and dimethyl trisulfide were potent inhibitors of yeast growth with minimum inhibitory concentrations between 2 and 45 ppm (Kim et al. 2004). Film formation on soy sauce by *Zygosaccharomyces rouxii* SS1 was completely prevented for 30 days by the addition of 30 and 40 ppm of garlic oil and onion oil, respectively. The oils and their constituent sulfides, however, were only very weakly antibacterial, showing minimum inhibitory concentrations of greater than 300 ppm for most of the bacteria tested.

Among the tested *Allium* oils, *A. sativum* f. *pekinense* oil exhibited the strongest inhibition of growth of *Trichophyton rubrum*, *T. erinacei* and

T. soudanense with MICs (minimum inhibiting concentrations) of 64 µg/mL (Pyun and Shin 2006). Additionally, garlic oils showed significant synergistic antifungal activity when combined with ketoconazole. Ethanol extracts of *Allium sativum*, *Aloe barbadensis* and *Solanum nigrum* were found to be inhibitory in-vitro to the following fungi: *Trichophyton rubrum*, *Trichophyton verrucosum*, *Trichophyton violaceum*, *Trichophyton tonsurans*, *Trichophyton mentagrophytes*, *Aspergillus glaucus*, *Aspergillus flavus*, *Aspergillus fumigatus*, *Aspergillus terreus*, *Candida albicans*, *Candida glabrata* and *Candida tropicali*s (Shamim et al. 2004). However, none of the plant extracts were found active against *Epidermophyton floccosum*.

The fungus *Fusarium oxysporum* showed the lowest sensitivity towards garlic essential oil extracts, whereas *Aspergillus niger* and *Penicillium cyclopium* were significantly inhibited particularly at low concentrations (Benkeblia 2004). A novel antifungal protein, designated allivin, from garlic bulbs, exhibited antifungal activity against *Botrytis cinerea*, *Mycosphaerella arachidicola* and *Physalospora piricola* (Wang and Ng 2001). It inhibited translation in a cell-free rabbit reticulocyte system with an IC_{50} of 1.6 µM. Compared to the garlic essential oil, the onion essential oil showed a stronger inhibitory effect on the *Aspergillus versicolor* mycelial growth and sterigmatocystin production. After a 21-day incubation of the fungus, 0.05 and 0.11 µg/mL of onion essential oil and 0.11 µg/mL of garlic essential oil completely inhibited the *Aspergillus versicolor* mycelial growth and mycotoxin sterigmatocystin biosynthesis. The combination of essential oils of onion (75 %) and garlic (25 %) had a synergistic effect on the growth inhibition of *A. versicolor* and sterigmatocystin production. Garlic essential oil, containing diallyl sulfides, exhibited antifungal effect against standard and wild strains of *Ascosphaera apis*, the fungal pathogen of chalkbrood disease (Kloucek et al. 2012).

Animal Studies

Oral treatment of BALB/c mice with garlic extracts showed that alcoholic garlic extracts (5 mg/kg, 4 times daily) provided 100 % protection of mice against disseminated cryptococcosis (Khan and Katiyar 2000). A concomitant increase in MST (mean survival time) (>35 days) was observed, along with a significant reduction in cfu (log_{10}) burden of cryptococci in visceral (the liver, spleen, kidney, lung and heart) tissues, especially the brain (>4.5 log_{10}). Ajoene treatment of mice intratracheally infected with *Paracoccidioides brasiliensis* was found to be effective in suppressing infection (Thomaz et al. 2008). Ajoene-treated mice developed Th1-type cytokine responses producing higher levels of IFN-γ and IL-12. Ajoene in association with antifungal drugs (sulfamethoxazole/trimethoprim) showed a positive additive effect. The efficacy of extracts was also evident in the sera of mice.

Allicin from crushed garlic clove inhibited the in-vitro growth of 31 clinical isolates of *Aspergillus* spp. (Shadkchan et al. 2004). The in-vitro MICs and MFCs of allicin were between 8 and 32 mg/L. Allicin intravenous (i.v.) treatment led to a significant 10-fold reduction in fungal burden in *A. fumigatus*-infected mice as evaluated by quantitative fungal cultures of kidney tissue samples. Allicin treatment significantly prolonged survival of infected mice from mean survival time (MST) = 7.7 days in untreated mice to MST = 21.3 and 13.9 days for allicin i.v. and orally treated mice. In immunosuppressed mice infected intranasally with conidia of *Aspergillus fumigatus*, intratracheal (i.t.) instillation of antibody–alliinase conjugate and alliin (four treatments) resulted in 80–85 % animal survival (36 days), with almost complete fungal clearance (Appel et al. 2010). Repetitive intratracheal administration of the conjugate and alliin was also effective when treatments were initiated at a more advanced stage of infection (50 hours). The fungus was killed specifically without causing damage to the lung tissue or overt discomfort to the animals. Intratracheal instillation of the conjugate without alliin or of the unconjugated monoclonal antibody significantly delayed the death of the infected mice, but only 20 % of the animals survived. In-vitro studies showed that the purified antibody–alliinase conjugate bound to conidia and hyphae of *A. fumigatus* at nanomolar

concentrations. In the presence of alliin, the conjugate produced cytotoxic allicin molecules, which killed the fungus.

Clinical Studies

The use of ajoene as a 0.4 % (w/w) cream resulted in complete clinical and mycological cure of tinea pedis in 27 of 34 patients (79 %) after 7 days of treatment (Ledezma et al. 1996). The remaining seven patients (21 %) achieved complete cure after seven additional days of treatment. In a randomised comparative study of 60 soldiers with clinical and mycological diagnosis of either tinea cruris and tinea corporis, 30 days after topical treatment, the percent healing rate was 77 and 75 for the groups treated with ajoene and terbinafine, respectively (Ledezma et al. 1999). Sixty days after treatment, the healing rate was 73 % and 71 % for the groups treated with ajoene and terbinafine, respectively.

In a 2-week randomised placebo-controlled double-blind trial of women with vulvovaginal candidiasis, oral ingestion of garlic tablets yielded no difference between the proportion of cases in the garlic and placebo groups, in the mean colony counts in both groups, or difference in the number of women reporting abnormal vaginal symptoms during the 2 weeks before menstruation (Watson et al. 2014).

Antibacterial Activity

A freshly prepared infusion of ground garlic cloves was found to possess high antibacterial activity (Cavallito and Bailey 1944; Cavallito et al. 1944, 1945). The active principle was identified as allicin. Maximal death rates of *Salmonella typhimurium* with freshly reconstituted dehydrated onion and garlic powders occurred at concentrations of 5 and 10 % (Johnson and Vaughn 1969). At these concentrations, the decimal reduction times were 1.1 and 1.2 hour, respectively, for resting cell cultures and 1.8 and 2.1 hour, respectively, for growing cultures. At comparable concentrations, growing cultures of *Escherichia coli* were as susceptible to garlic, but apparently more resistant to onion than were those of *S. typhimurium*. All extracts of garlic bulb were inhibitory in-vitro to *Escherichia coli*, *Pseudomonas pyocyaneus*, *Salmonella typhi* and *Bacillus subtilis* (Abdou et al.1972). Garlic extract concentrations higher than 1 % were inhibitory for *Lactobacillus plantarum*, while concentrations between 2 and 5 % were definitely germicidal (Karaioannoglou et al. 1977). Under favourable conditions garlic extract had a less inhibitory or germicidal effect upon *L. plantarum*. Large inocula (>106 cells/mL) were able to overcome the inhibitory effects of garlic extract in concentrations of 1 %. Garlic oil inhibited the in-vitro growth of *Lactobacillus plantarum*, *Saccharomyces cerevisiae*, *Aspergillus niger*, *Escherichia coli*, *Bacillus cereus* and *Pseudomonas aeruginosa* (Pátkai et al. 1998). The organoleptically optimal concentration of garlic oil made by extraction was high enough to ensure microbiological stability of ketchup.

All test organisms, five Gram-negative and three Gram-positive bacterial species (including *Staphylococcus aureus*, *Pseudomonas aeruginosa*) and two yeast species, were inhibited by garlic juice, while onion and shallot juice showed no effect upon Gram-negative bacteria (Dankert et al. 1979). Garlic extract showed greater activity against Gram-positive organisms and Gram-negative organisms as compared to the extract of onion (Elnima et al. 1983). Studies conducted on the comparative action of raw garlic extract and tetracycline hydrochloride on equal concentrations on caecal microflora of albino rats showed raw garlic extract to be a more potent antimicrobial agent than tetracycline (Shashikanth et al. 1984). A mouthwash containing 10 % garlic in quarter Ringer solution produced a drastic reduction in the number of oral bacteria. The ether extract gave the strongest inhibition followed by chloroform and petroleum ether extract. Garlic extract was found inhibitory to six strains of *Mycobacterium tuberculosis* with an MIC of 1.67 mg/mL (Delaha and Garagusi 1985). Diallyl thiosulfinate (allicin) was reported as the agent in garlic responsible for the antibacterial and antifungal activity of garlic extracts (Feldberg et al. 1988).

The water, ethanol and chloroform extracts of garlic exhibited antibacterial activity against the nosocomial *S. aureus*, *E. coli*, *S. pneumoniae* and *P. aeruginosa* (El-Mahmood 2009). The MBC values of the aqueous extract for *S. aureus* was 75 mg/mL; *S. pneumoniae*, 100 mg/mL; *E. coli*, 125 mg/mL; and *P. aeruginosa*, 150 mg/mL. The water extract was more potent than the organic extracts, and all were inferior in activity, when compared to the standard antibiotic, metronidazole. The Gram-positive *S. aureus* was more susceptible to the toxic effects of garlic than its Gram-negative counterparts. Gram-negative diarrhoeagenic pathogens *Escherichia coli*, *Shigella* sp., *Salmonella* sp. and *Proteus mirabilis* from stool samples were highly sensitive to garlic (Eja et al. 2007). No isolates were resistant to garlic, making it a promising antimicrobial agent. Aqueous garlic extract showed concentration-dependent inhibitory activity against *Staphylococcus aureus* in-vitro (Derese 2010). Garlic extract and streptomycin were found to have synergistic effect against streptomycin-resistant strains of *Staphylococcus aureus* and *Escherichia coli* (Palaksha et al. 2010). The garlic ethanolic extract demonstrated antibacterial activity in-vitro against all tested food-associated bacteria with maximum zone of growth inhibition ranging from 20 to 31 mm: *Bacillus subtilis* (31 mm), *Escherichia coli* (30 mm), *Staphylococcus aureus* (28 mm), *Bacillus polymyxa* (21 mm), *Bacillus megaterium* (20 mm) and *Bacillus sphaericus* (20 mm) (Pundir et al. 2010). Aqueous garlic extract exhibited antibacterial activity against Gram-positive (*Bacillus subtilis*, *Staphylococcus aureus*) and Gram-negative (*Escherichia coli* and *Klebsiella pneumonia*) strains and antifungal activity against *Candida albicans* (Meriga et al. 2012). The methanol extract showed antimicrobial activity against all the tested microorganisms except two (*Staphylococcus aureus* and *Candida albicans*), and the extracts of hexane, chloroform and ethyl acetate did not show any antimicrobial activity. Minimum inhibitory concentration of aqueous and methanol extracts against tested bacterial and fungal strains was 100–150 µg/mL.

All food bacterial pathogenic strains tested, namely, *Staphylococcus aureus*, *Salmonella typhi*, *Escherichia coli* and *Listeria monocytogenes*, were inhibited by garlic; *E. coli* was the most sensitive and *Listeria monocytogenes* was the least sensitive (Kumar and Berwal 1998). Garlic essential oil and nisin possessed considerable antimicrobial effects against *Listeria monocytogenes* (Rohani et al. 2011). The MICs for nisin and garlic oil were 12.5 IU/mL and 100 µg/mL, respectively. The combination of nisin with garlic oil at 30 °C, pH 5.6 and 0 g/100 mL NaCl showed significant anti-listerial activity.

The use of powder from fresh garlic was more effective for antibacterial activity against *Escherichia coli* than that from old garlic, the 1 % solution of fresh garlic powder eradicating the bacterium in 6 hours (Sasaki et al. 1999). The antibacterial activity was resistant to heat treatment of 100 °C for 20 minutes. The antibacterial activity of garlic powder was also shown against other types of pathogenic bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA), *Salmonella enteritidis* and *Candida albicans*. On the agar plate test, 1–5 % garlic powder inhibited the growth of *Bacillus anthracis* and *Escherichia coli* O157 (Sasaki and Kita 2003). A number of intestinal bacteria in a BALB/c mouse decreased after the oral administration of 1 mL of 1 % garlic powder solution once a day for 3 days.

Garlic extract was inhibitory to bacteria (Rees et al. 1993). The minimum inhibitory concentration (MIC) values for bacteria at 24 hours was 0.8–1 mg/mL for *Staphylococcus aureus* (two strains), 1–2.2 mg/mL for *Escherichia coli* (three strains), 1.8 mg/mL for *Bacillus cereus*, 1.8 mg/mL for *Bacillus subtilis*, 1.9 mg/mL for *Proteus mirabilis*, 2.3 mg/mL for *Listeria monocytogenes*, 2.4 mg/mL for *Salmonella enteritidis*, 2.3 mg/mL for *Salmonella dublinii*, 2.8 mg/mL for *Salmonella typhimurium* and 3.3 mg/mL for *Klebsiella aerogenes*. The following were less sensitive to garlic extract with MICs of 9.1 mg/mL for *Pseudomonas aeruginosa*, 12.5 mg/mL for *Lactobacillus plantarum*, 16.7 mg/mL for *Lactobacillus acidophilus*, 17.5 mg/mL for

Lactobacillus casei, 18.5 mg/mL for *Enterococcus faecium* and 34.5–39.7 mg/mL *Pedicoccus pentosaceus* (two strains). In mixed cultures of *E. coli* and *L. acidophilus*, garlic prevented the establishment of *E. coli*, although the final outcome of completion was not affected. In in-vitro pure culture studies, the beneficial gut bacterium *Lactobacillus casei* was found to be resistant to garlic powder, whereas rapid killing and reduction in cell numbers were observed with commensal bacteria *Bacteroides ovatus*, *Bifidobacterium longum* and *Clostridium nexile* (Filocamo et al. 2012). Lactic acid bacteria were found to be more resistant to garlic powder compared to the clostridial members of the gut microbiota. Studies showed that the efficacy of garlic juice was higher than chlorhexidine against target bacteria and could be used as an effective mouthwash (Amin et al. 2012). The lowest MIC of garlic juice was for *Streptococcus mutans* 0.25 µg/mL and the highest was for *Lactobacillus casei* 2.5 µg/mL. The MIC of chlorhexidine for these two bacteria was 0.62 µg/mL and 5 µg/mL, respectively. The MBC of chlorhexidine and garlic for *S. mutans* was 0.35 µg/mL and 0.3 µg/mL, respectively. The highest MBC of chlorhexidine was for *Streptococcus salivarius* 10 µg/mL. The MBC of garlic for *Streptococcus sanguis* was similar at 10.4 µg/mL.

Inhibition of RNA synthesis was found to be the primary target of allicin in *Salmonella typhimurium*. The growth of *Staphylococcus aureus* was inhibited by dehydrated garlic at levels of 1.5 % (w/v) and over (González-Fandos et al. 1994). Enterotoxins A, B and C1 were only detectable in broth containing <1 % of garlic, while enterotoxin D was produced at a level of 2 %. Garlic also inhibited thermonuclease (TNAse) production, complete inhibition being observed at levels > or = 1.5 %. The fresh aqueous garlic extract, 57.1 % (w/v), containing 324 µg/mL allicin inhibited the growth and killed most of the tested *Salmonella* serovars, namely, *Salmonella cerro*, *Salmonella enteritidis*, *Salmonella lindenberg*, *Salmonella montevideo*, *Salmonella hadar* and *Salmonella nikolaifleet* isolated from Tunisian fast foods, coproculture and wastewater (Belguith et al. 2010). The minimal inhibitory concentration and minimum bactericidal concentrations were very close, garlic MIC range 10–12.5 mg/mL and MBC range 13–15 mg/mL. Garlic extract could be stored at 4 °C because no detectable loss of antibacterial activity at this temperature over several days was observed. However, excessive warming or longer periods at higher temperatures should be avoided.

Garlic extracts exhibited antibacterial activity against food pathogens *Staphylococcus aureus*, *Escherichia coli*, *Salmonella typhi* and *Bacillus cereus* (Gomaa and Hashish 2002). Results showed that the higher the garlic concentration, the higher was the microbial reduction percent. Water extract of garlic exhibited a higher microbial reduction percentage than fresh garlic. In-vitro studies demonstrated that allicin could inhibit early bacterial adhesion, reduce extracellular polysaccharide substance secretion and downregulate quorum-sensing controlled virulence factor production of *Pseudomonas aeruginosa* (Lin et al. 2013). Collectively, these findings suggested the potential of allicin as a therapeutic agent for controlling *P. aeruginosa* biofilm. The ethanolic garlic extract was more effective than the aqueous garlic extract, inhibiting all the test organisms, *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Klebsiella pneumoniae* in-vitro, while the aqueous extract was not inhibitory to *Staphylococcus aureus* (Arekemase et al. 2013). *Allium sativum* essence oil (AEO) exhibited antimicrobial activity against beef-related bacteria, namely, *Listeria monocytogenes*, *Escherichia coli* and *Brochothrix thermosphacta* (Sung et al. 2014). Low-density polyethylene/ethylene vinyl acetate (LDPE/EVA) co-polymer film with 8 % AEO significantly reduced the concentration of bacteria with inhibition strength of *L. monocytogenes* > *B. thermosphacta* > *E. coli*. Except *Enterobacter faecalis* all the bacteria tested *Escherichia coli*, *Pseudomonas aeruginosa*, *Proteus mirabilis*, *Klebsiella* sp., *Staphylococcus aureus* and *Bacillus subtilis* were susceptible to crude garlic extract (Karuppiah and Rajaram 2012). The highest inhibition zone

was observed with garlic (19.45 mm) against *Pseudomonas aeruginosa*, and the minimal inhibitory concentration was as low as 67.00 μg/mL.

Ajoene at <20 μg/mL inhibited the growth of Gram-positive bacteria, such as *Bacillus cereus*, *Bacillus subtilis*, *Mycobacterium smegmatis* and *Streptomyces griseus* (Naganawa et al. 1996). *Staphylococcus aureus* and *Lactobacillus plantarum* were also inhibited at this concentration. For Gram-negative bacteria, such as *Escherichia coli*, *Klebsiella pneumoniae* and *Xanthomonas maltophilia*, MICs were between 100 and 160 μg/mL. Ajoene also inhibited yeast growth at concentrations below 20 μg/mL. *B. cereus* and *Saccharomyces cerevisiae* were killed at 30 μg/mL after 24 hours of cultivation. However, the minimal microbicidal concentrations for resting cells were at 10–100 times higher concentrations than the corresponding MICs.

E-4,5,9-trithiadeca-1,7-diene-9-oxide isolated from oil-macerated garlic extract exhibited antimicrobial activity against Gram-positive bacteria, such as *Bacillus cereus*, *B. subtilis* and *Staphylococcus aureus* and yeasts at the concentration lower than 100 μg/mL, but Gram-negative bacteria were not inhibited at the same concentration (Yoshida et al. 1999a). Its antimicrobial activity was inferior to those of similar oil-macerated garlic extract compounds such as *E*-ajoene, *Z*-ajoene and *Z*-10-DA. *Z*-10-DA exhibited a broad spectrum of antimicrobial activity against such microorganisms as Gram-positive and Gram-negative bacteria and yeasts (Yoshida et al. 1998). The antimicrobial activity of *Z*-10-DA was comparable to that of *Z*-ajoene, but was superior to that of *E*-ajoene. Antimicrobial activity of 2-propenesulfinothioic acid S-methyl ester [AllS(O)SMe] and 2-propene-1-sulfinothioic acid S-(*Z*,*E*)-1-propenyl ester [AllS(O)SPn-(*Z*,*E*)] isolated from oil-macerated garlic extract was comparable and inferior to that of allicin, respectively (Yoshida et al. 1999b). The result suggested that the antimicrobial activity of 2-propene sulfinothioic acid S-alk(en)yl esters was affected by alk(en)yl groups.

Although the antimicrobial effects of phytoalexin, allixin was weak (Kodera et al. 1989, 2002a), and the amount of allixin accumulated on the surface of the stored garlic clove was sufficient to protect against the invasion of microorganisms, i.e. almost ten times the antimicrobial activity level and higher than the MIC of allixin (MIC, 160 mg/mL; *Aspergillus niger*, 100 mg/mL; *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli*, 80 mg/mL; *Candida albicans*, no MIC data (Kodera et al. 2002a)). *Lactobacillus acidophilus*, a homofermentative organism, produced lactic acid that lowered the pH of the culture medium, resulting in a reduction in numbers of *Candida albicans* and *Escherichia coli* in mixed culture (Elsom et al. 2003). When the extract of garlic was added at a concentration of 2.56 μg, total thiosulfinate/mL for *C. albicans* in mixed culture and at a concentration of 5.12 μg total thiosulfinate/mL for *E. coli* in mixed culture, the reduction in cell numbers of both *C. albicans* and *E. coli* was accelerated. After 4 hours no *C. albicans* cells were countable, while *E. coli* cells were absent after 24 hours. Of several commercial preparations of garlic, which included oil macerates, pastes, tablets and powders, only the garlic tablet formulation exhibited good anticandidal and antiplatelet activity, whereas all the other preparations possessed virtually no anticandidal and antiplatelet properties.

The garlic constituents all showed substantial but widely differing anti-*Helicobacter pylori* effects against all strains and isolates tested (O'Gara et al. 2000). The MICs (range, 8–32 μg/mL) and minimum bactericidal concentrations (MBCs) (range, 16–32 μg/mL) of undiluted garlic oil (GO) were smaller than those of garlic powder (GP) (MIC range, 250–500 μg/mL; MBC range, 250–500 μg/mL) but greater than the MIC of allicin (4. 0 μg/mL) present in GP. Allicin (MIC, 6 μg/mL; MBC, 6 μg/mL) was more potent than diallyl disulfide (MIC range, 100–200 μg/mL; MBC range, 100–200 μg/mL), its corresponding sulfide, but of a strength similar to that of diallyl tetrasulfide (MIC range, 3–6 μg/mL; MBC range, 3–6 μg/mL). Antimicrobial activity of the diallyl sulfides increased with the number of sulfur atoms.

Garlic compounds diallyl sulfide and diallyl disulfide decreased arylamine N-acetyltransferase activity in strains of *Helicobacter pylori* from peptic ulcer patients (Chung et al. 1998). Viability studies on *H. pylori* demonstrated that DAS or DADS elicited dose-dependent bactericidal affects on *H. pylori* cultures. The concentration of aqueous garlic extract required to inhibit *Helicobacter pylori* growth was between 2 and 5 mg/mL, and the concentration to inhibit 90 % (MIC_{90}) of *H. pylori* isolates was 5 mg/mL (Cellini et al. 1996). The minimum bactericidal concentration (MBC) was usually equal to or twofold higher than the minimum inhibitory concentration (MIC). Heat treatment of extracts reduced the inhibitory or bactericidal activity against *H. pylori*; the boiled garlic extract showed a loss of efficacy from two- to fourfold the values of MIC and the MBC obtained with fresh garlic. A synergistic effect was found with garlic in after combination with a proton pump inhibitor (omeprazole) in a ratio of 250:1 in 47 % of *H. pylori* strains. MIC values of raw garlic extract and three types of commercial garlic tablets on *Helicobacter pylori* ranged from 10,000 to 17,500 mg/L (Jonkers et al. 1999). The combination of garlic and omeprazole, studied with killing curves, showed a synergic effect which was concentration dependent. Some oil-macerated garlic constituents (OMGE) inhibited the in-vitro growth of *Helicobacter pylori* isolates (Ohta et al. 1999). The vinyldithiins and 2-propene-1-sulfinothioic acid *S*-(*E*,*Z*)-1-propenyl ester [AllS(O)SPn-(*E*,*Z*)] were not inhibitory. The MIC values determined were ajoenes, *Z* ajoene (15-20 μg/mL), *E*-ajoene (25 μg/mL), *Z*-10-DA (15-20 μg/mL) and Iso-*E*-10-DA (10-15 μg/mL); vinyldithiins, 2-Vinyl-4*H*-1,3-dithiin and 3-Vinyl-4*H*-1,2-dithiin (>100 μg/mL); and thiosulfinates, AllS(O)SPn-(*Z*,*E*) AllS(O)SPn-(*Z*,*E*) (>100 μg/mL), 2-propene-1-sulfinothioic acid *S*-methyl ester [AllS(O)SMe] (20–25 μg/mL) and allicin (not a constituent of OMGE) (20–30 μg/mL). Allicin and allyl-methyl plus methyl-allyl thiosulfinate from acetonic garlic extract inhibited the in-vitro growth of *Helicobacter pylori*, the bacterium responsible for serious gastric diseases such as ulcers and even gastric cancer (Cañizares et al. 2004). Additionally, these compounds showed a synergistic effect on the inhibition of the in-vitro growth of the bacterium. Allitridin exhibited dose-dependent inhibitory activity against *Helicobacter pylori*, and its bacteriostatic mechanism could be attributed to its multitarget inhibitory effects in energy metabolism and biosynthesis including amino acid biosynthesis, protein synthesis, mRNA synthesis and fatty acid biosynthesis (Liu et al. 2010). Allitridin could also disrupt the expression of antioxidant proteins and decrease the production of virulence factors.

The essential oil extracts of these *Allium* plants (garlic and green, yellow, red onions) exhibited marked antibacterial activity against *Staphylococcus aureus* and *Salmonella enteritidis*, with garlic showing the highest inhibition and green onion the lowest (Benkeblia 2004). Comparatively, 50 and 100 mL/L concentrations of onions extracts were less inhibitory than 200, 300 and 500 mL/L concentrations. However, with garlic extract, high inhibitory activity was observed for all tested concentrations. *S. aureus* showed less sensitivity towards essential oil extract inhibition; however, *S. enteritidis* was strongly inhibited by red onion and garlic extracts. The protein alliumin, isolated from garlic bulb, was inhibitory in-vitro to the bacterium *Pseudomonas fluorescens* (Xia and Ng 2005). Garlic extract (57.1 % (w/v), containing 220 μg/mL allicin), inhibited the growth and killed most of the oral bacterial species tested (Bakri and Douglas 2005). In general, the minimal inhibitory and minimum bactericidal concentrations for the Gram-negative strains (garlic MIC range 35.7–1.1 mg/mL, allicin mean MIC 4.1 μg/mL, mean MBC 7.9 μg/mL) were lower than those for the Gram-positive strains tested (garlic MIC range 142.7–35.7 mg/mL, allicin mean MIC 27.5 μg/mL, mean MBC 91.9 μg/mL). Also, of the organisms tested, the putative periodontal pathogens had among the lowest MICs (17.8–1.1 mg/mL garlic) and MBCs (35.7–1.1 mg/mL garlic). Time-kill curves for *Streptococcus mutans* and *Porphyromonas gingivalis* showed that killing of the latter started almost immediately,

whereas there was a delay before *S. mutans* was killed. The garlic extract also inhibited the trypsin-like and total protease activity of *P. gingivalis* by 92.7 % and 94.88 %, respectively. Ethanolic garlic extract (EGE) and aqueous garlic extract (AGE) exhibited inhibitory effects against two periodontal pathogens *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans* (Shetty et al. 2013). AGE showed greater bacteriostatic activity against the *P. gingivalis* with minimum inhibitory concentration determined at 16.6 µL/mL. AGE showed better antiproteolytic activity on total protease of *P. gingivalis* compared to the EGE. All cariogenic isolates, MDR (multidrug resistant) and non-MDR, of *Streptococcus mutans* were sensitive to garlic extract with the MIC ranging from 4 to 32 µg/mL, whereas chlorhexidine minimum inhibitory concentration (MIC) for MDR and non-MDR *S. mutans* varied from 2 to 16 µg/mL and from 0.25 to 1 µg/mL, respectively (Fani et al. 2007). The results indicated that mouthwashes or toothpaste containing optimum concentration of garlic extract could be used for prevention of dental caries.

A new, stable, aqueous extract of allicin (extracted from garlic) showed potent in-vitro inhibitory activity against clinical isolates of methicillin-resistant *Staphylococcus aureus* that showed a range of susceptibilities to mupirocin (Cutler and Wilson 2004). Of the strains tested, 88 % had MICs for allicin liquids of 16 µg/mL, and all strains were inhibited at 32 µg/mL. Furthermore, 88 % of clinical isolates had MBCs of 128 µg/mL, and all were killed at 256 µg/mL. The antibacterial activity of crushed fresh garlic cloves and allicin (allyl 2-propenylthiosulfinate), a major antibacterial principle, declined on a daily basis in aqueous and ethanolic solutions at room temperature, showing biological and chemical half-lives of about 6 and 11 days, respectively (Fujisawa et al. 2008). Allicin was more stable in 20 % alcohol than in water, but surprisingly unstable in vegetable oil, with an activity half-life of 0.8 hour, as estimated from its antibacterial activity towards *Escherichia coli*, and a chemical half-life of 3.1 hour.

Garlic oil, Chinese leek (*Allium odorum*) oil and four diallyl sulfides occurring naturally in these oils exhibited in-vitro antimicrobial activity against *Staphylococcus aureus*, methicillin-resistant *S. aureus* (MRSA), *Candida albicans*, *C. krusei*, *C*, *glabrata*, *Aspergillus niger*, *A. flavus* and *A. fumigatus* (total of 276 clinical isolates) (Tsao and Yin 2001b). The magnitude of activity of the four diallyl sulfides followed the order diallyl tetrasulfide > diallyl trisulfide > diallyl disulfide > diallyl monosulfide. The concentration of four diallyl sulfides in garlic and Chinese leek oils was in the range 41.7–52.7 % of total sulfides. Garlic oil, with a higher concentration of four diallyl sulfides, showed greater antimicrobial activity than Chinese leek oil. Garlic oil at 4 x MIC could reduce original inoculum to < or =2 $\log_{10}$ in both *Pseudomonas aeruginosa* and *Klebsiella pneumoniae* within 8 hours (Tsao and Yin 2001a). The MIC values of four diallyl sulfides from garlic oil against these two pathogens followed the order diallyl monosulfide > diallyl disulfide > diallyl trisulfide (DAT) > diallyl tetrasulfide (DATS). Most interactions of ceftazidime, gentamicin, imipenem and meropenem with DAT or DATS, determined according to the fractional inhibitory concentration index, showed synergic or additive effects. The results suggested that garlic oil, DAT and DATS may have potential for the prevention or treatment of nosocomial, antibiotic-resistant bacterial infections. Garlic essential oil showed good antimicrobial activity in-vitro against *Staphylococcus aureus* (inhibition zone 14.8 mm), *Pseudomonas aeruginosa* (inhibition zone 21.1 mm) and *Escherichia coli* (inhibition zone 11.0 mm) (Casella et al. 2013). The main constituents of garlic oil were diallyl monosulfide, diallyl disulfide (DADS), diallyl trisulfide and diallyl tetrasulfide, and the results showed that the presence of the allyl group was fundamental for the antimicrobial activity of these sulfide derivatives. DADS had an inhibition zone of 15.9 mm on *S. aureus*, 21.9 mm on *P. aeruginosa* and 11.4 mm on *E. coli*. The dipeptide, (R)-3-(allylthio)-2-((R)-3-(allylthio)-2-aminopropanamido)propanoic acid, isolated from garlic bulb, showed antibacterial activity against the *Staphylococcus*

aureus antibiotic-resistant strain (Zhou et al. 2014a).

Except *Enterobacter* sp. and *Klebsiella* sp., *Escherichia coli*, *Pseudomonas aeruginosa*, *Proteus* sp., *Staphylococcus aureus* and *Bacillus* sp. were susceptible when subjected to ethanolic extracts of garlic and ginger (Karuppiah and Rajaram 2012). The highest inhibition zone was observed with garlic (19.45 mm) against *P. aeruginosa* with minimal inhibitory concentration of 67.00 µg/mL. Diallyl disulfide complex exhibited significant antibacterial activity (MIC 100 µg/ mL) and was found to be effective against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae* and *Escherichia coli* (Singh et al. 2012).

Animal Studies

Aqueous garlic extract of garlic and allicin both showed significant in-vitro antibacterial activity against isolates of multiple drug-resistant *Shigella dysenteriae* 1, *Shigella flexneri* Y, *Shigella sonnei* and enterotoxigenic *Escherichia coli* (Chowdhury et al. 1991). The two agents also showed promising in-vivo antibacterial activity against *Shigella flexneri* Y when tested in the rabbit model of experimental shigellosis, fully curing the infected rabbits within 3 days.

Oral administration of garlic extract, diallyl sulfide and diallyl disulfide possessed multiple protective functions against methicillin-resistant *Staphylococcus aureus* (MRSA) in rats (Tsao et al. 2003). Garlic significantly decreased the viability of MRSA, in the plasma, liver, kidney and spleen in MRSA-infected rats; significantly increased fibronectin and interleukin 6 levels in plasma; significantly enhanced lipid oxidation in plasma and three organs; and showed antioxidant protection in significantly decreasing the malondialdehyde level. The garlic-derived volatile allyl methyl sulfide (AMS) exhibited an antibacterial effect against the pig pathogen *Actinobacillus pleuropneumoniae* serotype 9 (Becker et al. 2012). Feeding garlic to pigs reduced *A. pleuropneumoniae* infection as indicated by the reduced occurrence of characteristic pleuropneumonia lesions (27 % of the lungs affected in the garlic-fed group vs. 47 % in the control group) and significantly lower relative lung weight postmortem in the garlic-fed group.

Diallyl sulfide (DAS) and diallyl disulfide (DADS), from garlic, inhibited methicillin-resistant *Staphylococcus aureus* (MRSA) infection in streptozotocin-induced diabetic mice (Tsao et al. 2007). DAS and DADS significantly decreased MRSA viability in the kidney, with administration of each agent twice showing a greater inhibitory effect than when given once. DAS and DADS treatments also significantly reduced the plasma levels of CRP, fibronectin and fibrinogen and the MRSA-elevated malondialdehyde levels in the kidney and spleen. DAS or DADS given twice significantly decreased the plasma levels of both IL-6 and TNF-α, and significantly increased AT-III and protein C activities. The data suggested that DAS and DADS could provide multiple protective functions against MRSA infection in diabetic mice.

Clinical Studies

Zhou (2003) reported the treatment of acute lymphangitis in 118 cases by moxibustion with garlic. Burning of moxa stick being itself antagonistic to bacteria could also promote the local flow of qi and blood and enhance the antagonistic effect of garlic on bacteria. A 2.5 % garlic mouthwash solution had good antimicrobial activity against *Streptococcus mutans* and other oral microorganisms in a 5-week study of 30 subjects (Groppo et al. 2007). Maintenance of reduced salivary levels of streptococci was observed after 2 weeks at the end of mouthwash use. Unpleasant taste (100 %), halitosis (90 %) and nausea (30 %) after using garlic mouthwash for 5 weeks were reported by subjects after the end of the study. It was concluded that the garlic cloves have antimicrobial properties in-vitro against streptococci and anticariogenic properties against oral microorganism in spite of its adverse effects. In a study involving 45 dental students using garlic extract mouth rinse daily for a week, posttreatment *Streptococcus mutans* counts showed that garlic was effective against *S. mutans* and could be used as an effective remedy in the prevention of dental caries (Chavan et al. 2010). In a clinical study of 100 married women, aged 18–44, whose infection

with diagnosed bacterial vaginosis, treatment with micosin vaginal cream (made of garlic) for 7 days appeared to be an appropriate alternative for metronidazole vaginal gel in treatment of bacterial vaginosis (Moori et al. 2010). In a clinical study of 140 burn patients, patients in the group with <45 % but >20 % of total body surface area that received two crushed garlic cloves mixed with yogurt with their daily lunch meal had significantly reduced *Pseudomonas aeruginosa* burn wound infection compared to the group with yogurt only. It seemed that fresh crushed garlic cloves could be used as a supplementary herbal medicinal agent in delaying of *P. aeruginosa* burn wound infection in patients with moderate burn injuries.

The findings from the cross-sectional study of 566 Japanese men aged 50–55 years suggested that fresh vegetables may be protective against *H. pylori* infection but did not support either an increased risk of the infection associated with salty foods or a protective effect of green tea or garlic (Shinchi et al. 1997). The prospective crossover study in healthy *Helicobacter pylori*-infected adults did not support a role for either garlic or jalapeños in the treatment of *H. pylori* infection (Graham et al. 1999).

Antiviral Activity

Garlic extract prevented infection by influenza B virus and herpes simplex virus but not against Coxsackie virus (Nagai 1973; Tsai et al. 1985). The order for virucidal activity for garlic-derived compounds against selected viruses including herpes simplex virus type 1, herpes simplex virus type 2, parainfluenza virus type 3, vaccinia virus, vesicular stomatitis virus and human rhinovirus type 2 generally was ajoene > allicin > allyl methyl thiosulfinate > methyl allyl thiosulfinate (Hughes et al. 1989; Weber et al. 1992). The 50 % endpoint neutralisation titre for porcine rotavirus strain OSU was 2.4–2.8 μg/mL garlic (Rees et al. 1993). Ajoene was found in oil macerates of garlic but not in fresh garlic extracts. No activity was found for the garlic polar fraction, alliin, deoxyalliin, diallyl disulfide or diallyl trisulfide. Fresh garlic extract, in which thiosulfinates appeared to be the active components, was virucidal to each virus tested. The predominant thiosulfinate in fresh garlic extract was allicin. In addition, concentrations that were virucidal were also toxic to HeLa and Vero cells. Shoji et al. (1993) found that allyl disulfide, allyl alcohol (both found in garlic) and its ester strongly depressed cell proliferation of HIV-1-infected cells. KC_{50} (50 % killing concentration) of the allyl disulfide and the allyl alcohol were 34 μM and 10 μM, respectively. The allyl alcohol, in particular, completely inhibited cell growth of HIV-1-infected cells by a single injection at a concentration of 40 μM, ultimately killing the viable CEM/LAV-1 cells within 96 hours of cultivation. No effect of the allyl alcohol and its esters on cell proliferation of CEM cells, an HIV-1-noninfected human T-cell cell line, was observed at the concentration range of 20–200 μM under the same experimental conditions.

Racemic ajoene inhibited the fusion of H9 cells with HIV-infected H9:RF cells (IC_{50} approximately 45 μM; 16 hours of incubation) and also exhibited antiviral activity (IC_{50} approximately 5 μM as assessed by the inhibition of HIV-1/CEM/Lav 1 Bru replication in CEM13 cells; 72 hours) (Tatarintsev et al. 1992). Ajoene exhibited differential inhibitory activity in-vitro against human immunodeficiency virus (HIV)-1 (IIIB) (Walder et al. 1997). Ajoene protected acutely infected Molt-4 cells against HIV-1 and blocked further destruction of CD4 T cells in-vitro. Ajoene showed dose-dependent inhibition, with 50 % cytotoxic concentration ($CTC_{50\,\%}$) and 50 % effective inhibitory concentration ($EIC_{50\,\%}$) values of 1.88 μM and about 0.35 μM, respectively, when the test compound was added before or after HIV-1 infection and incubation carried out at 37 °C for 4 days. Ajoene proved relatively more active than dextran sulfate in blocking HIV-1 virus–cell attachment.

Z-ajoene inhibited human cytomegalovirus in-vitro mediated by an increased number of apoptotic cells after infection (Terrasson et al. 2007). Garlic extract exhibited dose-dependent antiviral activity against human cytomegalovirus (HCMV) in-vitro (Guo et al. 1993). Its bioactive compound

allitridin (diallyl trisulfide) dose dependently inhibited the virus with an EC_{50} value of 4.2 μg/mL (Zhen et al. 2006). Allitridin inhibited HCMV replication in the earlier period of viral cycle before viral DNA synthesis. Decrease of viral DNA load in infected cells was also detected under allitridin treatment, probably due to an indirect consequence of the reduction in IE gene transcription. Allitridin was found to effectively suppress the transcription of IE genes (ul122 and ul123) of HCMV AD169 strain, leading to a significant lowering of the mRNA expression (Zhang et al. 2011). It was able to suppress the transcription of IE gene (ul54) and l gene (ul83), indicating that HCMV IE genes may be the key target of allitridin against HCMV. In-vitro studies in HCVM-infected human embryo lung cells, HEL, showed that another mechanism of allitridin, anti-HCMV activity, was by the inhibition of HCMV immediate early antigen (HCMV-IEA) expression (Shu et al. 2003). The maximum tolerant concentration (MTC) of allitridin was 9.60 mg/L. Additionally, allitridin effectively suppressed the transcription of the HCMV IE, HCMV E and HCMV L genes; the inhibition rates of the transcription of the ul122 and ul123 genes were higher compared with those of ul54 and ul83 mRNA expression, while the expression of the IE genes was not significantly reduced by ganciclovir (GCV) (Zhang et al. 2013b). Further, their results indicated that the IE genes may be the key target of allitridin in its action against HCMV. Among five *Allium* plants tested, shallots exhibited the highest level of antiviral activity for both adenovirus ADV41 and ADV3, followed by garlic and onions (Chen et al. 2011).

In a 12-week, randomised, placebo-controlled study of 146 volunteers, volunteers taking placebo were much more likely to get more than one cold over the treatment period (Josling 2001). An allicin-containing supplement had significantly fewer colds than the placebo group and thus could prevent attack by the common cold virus.

In a self-controlled, longitudinal study nested within the Women's Interagency HIV Study, from October 1994 to April 2009, conducted by Liu et al. (2012a), short-term garlic supplementation was found not to impact on highly active antiretroviral treatment (HAART) adherence level and HAART effectiveness (HIV viral load and CD4+ cell counts) in HIV-infected women. However, 'use garlic as needed', a potential marker of a disease state was significantly associated with higher viral load.

Antithrombotic/Antiplatelet Activity

Anticoagulant factor of garlic extract exhibited anticoagulant activity in-vitro but not in-vivo, and two mechanisms for this activity suggested were by precipitating calcium ions and by causing fibrinolysis (Song et al. 1963a). Addition of essential oil of garlic dose dependently inhibited in-vitro platelet aggregation induced by ADP, epinephrine or collagen (Bordia 1978). Oral administration of garlic also decreased platelet aggregation. Incubation of platelet-rich plasma with garlic bulb extract either in methanol or in homologous platelet-poor plasma inhibited platelet aggregation induced by all of the agonists ADP, epinephrine, collagen, thrombin, arachidonate, PAF and the ionophore A-23187 (Apitz-Castro et al. 1983). Three pure components isolated from it F1, F2 and F3 also inhibit platelet aggregation; however, F3 was about four times more potent. Thrombin-induced release of ATP from gel-filtered platelets was inhibited by 75–80 % after garlic extract or F3 treatment. Chemical structures of F1, F2 and F3 were provisionally assigned as diallyl trisulfide for F1, 2-vinyl-1,3-dithiane for F2 and allyl 1,5-hexadienyltrisulfide for F3. The data suggest that the antiplatelet effects described might be mediated by a perturbation of the physicochemical properties of the plasma membrane rather than by affecting arachidonate or calcium metabolism in the cells.

Aqueous extracts of onion, garlic and ginger inhibited platelet aggregation induced by several aggregation agents, including arachidonate (AA), in a dose-dependent manner (Srivastava 1984). The three aqueous extracts inhibited the biosynthesis of 6-keto-F1 alpha in rat aortic rings from labelled AA, and they did not reduce prostacyclin production from endogenous AA pool in aortic rings. Aqueous extract of garlic inhibited aggregation induced by ADP, collagen,

arachidonate (AA), epinephrine and calcium ionophore A23187 in a dose-dependent manner (Srivastava 1986). It was found that garlic reduced the formation of thromboxane from exogenous AA; garlic inhibited the phospholipase activity; garlic inhibited the formation of thromboxane and lipoxygenase products formed in platelets prelabelled with AA; and garlic inhibited the incorporation of arachidonate into platelet phospholipids. These effects may explain, in part, inhibition of platelet aggregation. Further, garlic was also effective in inhibiting aggregation induced by calcium ionophore A23187 suggesting that the anti-aggregation effect may be related to the intraplatelet mobilisation of calcium. Inhibition of epinephrine-induced aggregation by garlic extract may suggest that it may be inhibiting the uptake of calcium into platelets thereby lowering cytosolic calcium concentrations. Two fractions obtained from the TLC of the aqueous garlic extract were found to be antiaggregatory on epinephrine- and arachidonic acid (AA)-induced aggregation (Srivastava and Justesen 1989). The material extracted in ether (MEE) inhibited the incorporation of labelled AA into platelets in platelet-rich plasma. Garlic extracts (MEE and material extracted in chloroform, MEC) at higher dosage inhibited the degradation of platelet phospholipids and reduced the formation of thromboxane (TxB2) and lipoxygenase-derived products from labelled platelets. The two organic extracts at low dosage, while not affecting the degradation of platelet phospholipids, inhibited the cyclooxygenase and lipoxygenase enzymes. A concomitant increase in the amount of released AA was observed in the treated platelets. Adenosine and allicin, from garlic and onions, both inhibited platelet aggregation without affecting cyclooxygenase and lipoxygenase metabolites of arachidonic acid (Makheja and Bailey 1990). The trisulfides inhibited platelet aggregation as well as thromboxane synthesis along with the induction of new lipoxygenase metabolites.

When added to platelet-rich plasma, aqueous extracts of garlic inhibited platelet aggregation and the release reaction (Mohammad and Woodward 1986). The inhibitory component was characterised as allicin. At 10 uM concentration, allicin inhibited completely platelet aggregation and the release reaction. Mayeux et al. (1988) reported that allicin inhibited human platelet aggregation in-vitro without affecting cyclooxygenase, thromboxane synthase activity or cyclic adenosine monophosphate (AMP) levels and without altering the activity of vascular prostacyclin synthase.

Raw garlic inhibited cyclooxygenase activity non-competitively and irreversibly in rabbit tissues (Ali 1995). A dose-dependent inhibition of cyclooxygenase activity was observed in tissues treated with raw garlic. The garlic concentrations required for 50 % inhibition of platelet, lung and vascular aortic cyclooxygenase activities of rabbits were 0.35, 1.10 and 0.90 mg, respectively. Cyclooxygenase activity of rabbit platelets was more sensitive to inhibition by raw garlic than the enzyme from blood vessels or lungs. Boiled garlic was found to have little effect on cyclooxygenase activity as compared to raw garlic in these tissues. The results indicated that garlic may be beneficial in the prevention of thrombosis if ingested raw rather in a cooked form.

Aged garlic extract (AGE) inhibited platelet aggregation in a concentration-dependent manner, and this achieved significance between concentrations of 1.56–25 % (v:v) (Allison et al. 2006a). AGE also displayed disaggregatory properties at concentrations of 12.5 and 25 % (v:v). The constituents and the amino acids, when tested as a mixture, displayed disaggregatory properties at concentrations of 0.25 and 1 mmol/L. In contrast, a diethyl ether extract of AGE had no effect on platelet aggregation. When platelets were stimulated with either A23187 or ADP, an increase in intraplatelet Ca2+ accompanied platelet aggregation. This increase in Ca2+ was abolished in the presence of AGE. It was concluded that AGE acted in a synergistic manner and exerted multiple effects on the biochemical pathways involved in platelet aggregation. Further they reported that aged garlic extract inhibited platelet aggregation either by suppressing the influx of calcium ions by chelating calcium within platelet cytosol or by altering other intracellular second messengers within the platelets (Allison et al. 2006b). Results of studies sug-

gested that odourless garlic not only activated fibrinolytic activity by accelerating tissue-type plasminogen activator (t-PA)-mediated plasminogen activation but also suppressed the coagulation system by downregulating thrombin formation, indicating a beneficial role in preventing pathological thrombus formation in such cardiovascular disorders (Fukao et al. 2007). Garlic exerted antiaggregatory effects in platelets taken from healthy volunteers via inhibition of the adenosine diphosphate (ADP) pathway; its mechanisms of action were comparable to that of the clinically used drug clopidogrel (Hiyasat et al. 2009). Studies showed that garlic extract showed significant fibrinolytic effect in-vitro compared with the control group (Ansari et al. 2012). Various concentrations of garlic extract exhibited significant different rise in the fibrinolytic activity of blood clot in different time. Desirable result was obtained in the lower concentration of (10 µg/µL) after 7 hours.

Garlic extracts contained a compound termed ajoene, which was found to be a potent inhibitor of platelet aggregation (Block et al. 1986). Ajoene, the major antiplatelet compound derived from garlic, synergistically potentiated the antiaggregatory action of prostacyclin, forskolin, indomethacin and dipyridamole (Apitz-Castro et al. 1986a). For collagen-induced platelet aggregation in human platelet-rich plasma, the ID_{50} for ajoene was 95 µM. However, in the presence of the antiaggregatory drugs mentioned above, the ID_{50} for ajoene decreased more than what would be predicted on the basis of simple additive effects. Further, ajoene inhibited the fibrinogen-supported aggregation of washed human platelets (ID_{50} = 13 µM) and inhibited binding of 125I-fibrinogen to ADP-stimulated platelets (ID_{50} = 0.8 µM) (Apitz-Castro et al. 1986b). In both cases, the inhibition was of the mixed non-competitive type. Fibrinogen-induced aggregation of chymotrypsin-treated platelets was also inhibited by ajoene in a dose-dependent manner (ID_{50} = 2.3 µM). Other membrane receptors such as ADP or epinephrine receptors were not affected by ajoene. Ajoene strongly quenched the intrinsic fluorescence emission of purified glycoproteins IIb–IIIa (ID_{50} = 10 µM). These results suggested that the antiaggregatory effect of ajoene was causally related to its direct interaction with the putative fibrinogen receptor. Ajoene inhibition of platelet aggregation was found to be possibly mediated by modifying the binding interactions of the haemoprotein with ligands (Jamaluddin et al. 1988). Administration of ajoene to heparinised pigs significantly prevented thrombus formation mainly in arterial sites with local low blood shear rates (Apitz-Castro et al. 1994). The results of in-vitro studies suggested that ajoene inhibited platelet release reaction by affecting the plasma membrane internal microviscosity, which impaired the fusion of the granules and plasma membrane, a prerequisite for exocytosis (Rendu et al. 1989). Ajoene was found to inhibit platelet aggregation induced by arachidonic acid (AA), adrenaline, collagen, adenosine diphosphate (ADP) and calcium ionophore A23187; the nature of the inhibition was irreversible (Srivastava and Tyagi 1993). In washed platelets stimulated by labelled arachidonate, ajoene inhibited the formation of thromboxane A2; 12-lipoxygenase product(s) was reduced at higher ajoene concentrations. Ajoene inhibited the incorporation of labelled AA into platelet phospholipids at higher concentration.

Steroidal saponins isolated from garlic, namely, proto-isoeruboside-B and isoeruboside-B, had no effect on platelet aggregation. Nevertheless, isoeruboside-B inhibited blood coagulation and had a fibrinolysis-promoting effect (Peng et al. 1996) with IC_{50} of 1.5 mg/mL for blood coagulation inhibition and IC_{50} of 19 mg/mL for fibrinolysis promoting activity (Peng and Yao 1996). Proto-isoeruboside-B was found to promote only fibrinolysis (Peng et al. 1996) with IC_{50} of 13 mg/mL (Peng and Yao 1996). Total garlic saponins and garlic adenosine had platelet aggregation activity with IC_{50} of 7.3 mg/mL and 1.87 mg/mL, respectively. Total garlic saponins and garlic adenosine also had fibrinolysis promoting activity with IC_{50} of 13 mg/mL and 25 mg/mL, respectively. *N*-feruloyltyramine isolated from garlic cloves, at the concentration of 0.05 µM was found to be a very potent compound able to inhibit COX-I and

-II enzymes by 43 % and 33 %, respectively (Park 2009). N-feruloyltyramine was found likely to inhibit COX enzymes, thereby suppressing P-selectin expression on platelets.

In platelet-rich plasma (PRP) most of the antiaggregatory activity of garlic clove homogenates was due to adenosine; however, in whole blood neither adenosine nor the polar fraction had any effect, and all of the antiaggregatory activity was due to allicin and other thiosulfinates (Lawson et al. 1992). Allicin was equally active in whole blood and PRP. The best garlic powder tablets were equally as active as clove homogenates, whereas steam-distilled oils were 35 % as active and oil macerates (due to low content) only 12 % as active. A garlic product aged many months in aqueous alcohol had no activity. For steam-distilled oils, most of the activity was due to diallyl trisulfide. For the oil macerates, most of the activity was due largely to the vinyldithiins. Ajoene, an exclusive component of the oil macerates, had the highest specific activity of all the compounds tested but, because of its low concentration, had only 13 % of the activity of diallyl trisulfide and 3 % of the activity of allicin.

In labelled platelets, on stimulation with either calcium ionophore A23187 or collagen, reduced amounts of thromboxane and 12-HETE (12-hydroxyeicosatetraenoic acid) were produced in ajoene-treated platelets compared to control platelets. In-vitro, ajoene at concentrations of > or =75 µg/mL inhibited baboon platelet aggregation by 95 % (ADP assay) and 89 % (collagen assay) (Teranishi et al. 2003). Ajoene also inhibited the aggregation caused by pig growth factor-mobilised peripheral blood leucocytes (containing 1–2 % progenitor cells) (pPBPC) by 33–50 %. In-vivo, platelet aggregation in baboon was completely inhibited for 2 hours by ajoene at 25 mg/kg. Dipyridamole at 0.8 mg/kg reduced aggregation by 20 % for 15 minutes, but the effect was lost by 60 minutes. In combination, the two agents prolonged inhibition marginally.

The antiplatelet activity of methyl allyl trisulfide (MATS), a component commonly present in steam-distilled garlic oil, was demonstrated by Ariga et al. (2000). MATS inhibited arachidonic acid cascade at the reaction site with prostaglandin H (PGH) synthase. However, this enzyme catalysed two successive reactions, from arachidonic acid to prostaglandin G_2 (PGG_2) and from PGG_2 to prostaglandin H_2 (PGH_2). Studies suggested that (1) allicin and thiosulfinates were responsible for in-vitro antiaggregatory activity response, (2) crushing garlic before moderate cooking could reduce the loss of activity and (3) the partial loss of antithrombotic effect in crushed-cooked garlic may be compensated by increasing the amount consumed (Cavagnaro et al. 2007).

A dose-dependent inhibition of rabbit platelet aggregation was observed with garlic (Ali et al. 1999). Garlic showed higher magnitude compared to dose-dependent inhibitory effects on the collagen-induced platelet aggregation than onion. The concentration required for 50 % inhibition of the platelet aggregation for garlic was calculated to be approximately 6.6 mg/mL plasma, whereas the concentration for onion was 90 mg/mL plasma. Boiled garlic and onion extracts showed a reduced inhibitory effect on platelet aggregation. The potency of garlic in inhibiting the collagen-induced platelet aggregation was approximately similar to that of rabbit platelets (8.8 mg/mL produced 50 % inhibition of platelet aggregation). The results showed that garlic was about 13 times more potent than onion in inhibiting platelet aggregation.

Animal Studies

In-vivo studies showed that pretreatment of rabbits with an aqueous extract of garlic (500 mg/kg) provided protection from thrombocytopenia and hypotension (Ali et al. 1990). Synthesis of thromboxane B2 during infusion of arachidonic acid and collagen was significantly inhibited. The findings showed that garlic may be beneficial in the prevention of thrombosis. Administration of aqueous extracts of garlic and onion, orally or intraperitoneally, daily for a period of 4 weeks exerted an antithrombotic on rats (Bordia et al. 1996). Thromboxane B2 (TXB2) level in the serum was inhibited, but boiled garlic and onion at high concentration (500 mg/kg) had a very little effect on TXB2 synthesis. Garlic was found to

be more potent than onion in lowering the TXB2 levels. Garlic inhibited the thrombin-induced platelet synthesis of thromboxane B(2) in a dose- and time-dependent manner in rabbits (Thomson et al. 2000). At 24 hours post-garlic infusion, TXB(2) inhibition was reduced to 15 % of the control, and TXB(2)levels were comparable to that of the control values at 72 hours post-garlic infusion. The rapid recovery of platelet cyclooxygenase activity after infusion of a single dose of garlic suggested that garlic should be taken more frequently in order to achieve beneficial effects in the prevention of thrombosis.

Garlic dialysate induced a drop in diastolic blood pressure (DBP) (from 112.5 to 70 mmHg) and a decrease in heart rate (HR) (from 198 to 164 beats/minute) in anaesthetised dog in a dose-dependent manner (Martin et al. 1992). The electrocardiogram (ECG) showed a regular sinus bradycardic rhythm. The addition of garlic dialysate to the isolated left rat atria evoked a decrease in tension development. Frequency, measured by spontaneous beating of the right atria, was also reduced. Both effects were dose dependent. Additionally, the positive inotropism and chronotropism induced by addition of isoproterenol 10^{-9} M were partially antagonised by preincubation of the rat atria with the garlic dialysate. The findings could be elucidated by a depressant effect on automaticity and tension development in the heart, suggesting a beta-adrenoceptor blocking action produced by the garlic dialysate. Further they found that the negative inotropism of garlic dialysate increased with calcium 0.75 mM; in contrast, high level of calcium (4.5 mM) induced a significant reduction of this depressant effect (Martin et al. 1997). Their findings suggested that the negative inotropic effect of our garlic dialysate was related to $[Ca^{2+}]O$ availability.

Diallyl trisulfide (DAT)-rich garlic oil at 5 or 50 mg garlic oil/kg body weight fed to Sprague–Dawley rats significantly prolonged the bleeding time and thrombin time and enhanced anticoagulation factor activity, such as antithrombin III and protein C (Chan et al. 2007). In addition, DAT-rich garlic oil benefited blood anticoagulation factors, which might further prevent the development of thrombus formation. However, the intake of garlic oil at high dose significantly increased plasma fibrinogen concentration and affected the levels of several haematological parameters such as erythrocyte count, haemoglobin and platelets. Therefore, the lower concentration of DAT-rich garlic oil should be used.

Clinical Studies

In a randomised, placebo-controlled, double-blind study, garlic consumption was found to improve blood fluidity and to increase fibrinolytic activity (Kiesewetter et al. 1990). In a double-blind, placebo-controlled study on 60 voluntary subjects with cerebrovascular risk factors and constantly increased platelet aggregation, it was demonstrated that the daily ingestion of 800 mg of powdered garlic in tablet from over 4 weeks led to a significant inhibition of the pathologically increased ratio of circulating platelet aggregates and of spontaneous platelet aggregation (Kiesewetter et al. 1993b). Consumption of 10 g of raw garlic daily after breakfast for 2 months elicited a significant decrease in serum cholesterol and an increase in clotting time and fibrinolytic activity in 50 human volunteers (Gadkari and Joshi 1991). In a randomised, double-blind, placebo-controlled cross-over study of 12 healthy subjects, Legnani et al. (1993) evaluated the acute and chronic effects of a preparation of dried garlic powder in a total daily dose of 900 mg on fibrinolysis and platelet aggregation. Total euglobulin fibrinolytic activity and TPA (tissue plasminogen activator) activity were significantly higher 4 and 6 hours after garlic and placebo ingestion, and no differences were recorded between treatments. After 14 days of treatment, TPA activity was significantly higher after garlic, with inter-treatment significance. No significant changes in PAI (plasminogen activator inhibitor) activity and fibrinogen levels were recorded. Platelet aggregation induced by adenosine diphosphate and collagen, and especially beta-thromboglobulin (beta-TG) release, after collagen stimulation was significantly inhibited 2 and 4 hours after garlic ingestion; platelet aggregation values were also significantly lower after 7 and 14 days of garlic

treatment. No significant changes were found in adenosine triphosphate release and serum thromboxane B2 levels after acute garlic administration. In another placebo-controlled, double-blind design study of feeding garlic extract to healthy men, no significant differences in platelet aggregation with adenosine diphosphate, platelet activating factor (PAF) or collagen according to treatment group were found (Morris et al. 1995). Serum thromboxane and lyso-platelet activating factor also showed no change related to garlic supplements. In-vitro aggregation with collagen decreased linearly with increasing amounts of garlic extract, but concentrations were higher than those attainable in-vivo. In a study of 60 patients with coronary artery disease (CAD) (30 garlic, 30 placebo), garlic supplementation reduced significantly total serum cholesterol and triglycerides and increased significantly HDL cholesterol and fibrinolytic activity (Bordia et al. 1998). In-vitro, garlic oil inhibited platelet aggregation induced by several platelet agonists and also platelet thromboxane formation. Two important garlic oil constituents, diallyl disulfide (DADS) and diallyl trisulfide (DATS), showed antiplatelet activity and also inhibited platelet thromboxane formation.

Steiner and Lin (1998) found that administration of aged garlic extract (AGE) to moderately hypercholesterolaemic men for 10 months had beneficial effects on lipid profile, blood pressure and platelet function. Supplementation of subjects with 7.2 AGE per day showed a significant reduction of epinephrine- and, to a lesser degree, collagen-induced platelet aggregation but failed to demonstrate an inhibition of adenosine diphosphate (ADP)-induced aggregation. Platelet adhesion to fibrinogen was reduced by approximately 30 % in subjects taking AGE compared with placebo supplement. A trend towards decreased susceptibility of lipoproteins to oxidation also was noted during AGE administration compared with the placebo period. In a randomised, double-blind, placebo-controlled clinical trial of 152 probationers, continuous intake of high-dose garlic powder dragées reduced significantly the increase in arteriosclerotic plaque volume by 5–18 % or even effected a slight regression within the observational period of 48 months (Koscielny et al. 1999). Also the age-dependent representation of the plaque volume showed an increase between 50 and 80 years that was diminished under garlic treatment by 6–13 % related to 4 years. Further in a randomised, double-blind study of normal healthy individuals ($n=34$), both men and women, they found that the adherence of platelets was inhibited by AGE in a dose-dependent manner when collagen was the adhesive surface perfused at low shear rates (approximately 30/s) (Steiner and Li 2001). At high shear rates (1,200/s), AGE also inhibited platelet adhesion to collagen but only at higher intake levels. Adhesion to von Willebrand factor was reduced only at 7.2 g/day AGE, but adherence to fibrinogen was potently inhibited at all levels of supplementation.

In a randomised, double-blind, placebo-controlled, crossover study of 14 healthy volunteers, four hours after consuming one large dose of oil derived from 9.9 g garlic, there was little or no effect in the reduction of platelet aggregation (Wojcikowski et al. 2007). Platelet aggregation induced by adrenaline was reduced slightly but significantly (12 % reduction). The oil had no effect on collagen- or ADP-induced aggregation. In a randomised, open-label, placebo-controlled, crossover study of type II diabetic patients, after single- and multiple-dose administration of aged garlic, there was a significant inhibition of platelet aggregation at 2 hours, whereas with cilostazol, the inhibition was significant at all the three time points tested, with 4 hours showing maximum inhibition (Mateen et al. 2011). Co-administration of aged garlic extract and cilostazol did not enhance the antiplatelet activity compared with individual drugs.

Review Studies

A review of studies of garlic (*Allium sativum*) on serum lipids and blood pressure before and after 1994 found that publications published prior to January 1994 performed better than those published after January 1994, suggesting that allicin may be responsible for the antihypertensive effects of garlic powder tablets (McRae 2005). However, a lack of correlation between changes

in total serum cholesterol and blood pressure suggested that other organosulfur compounds may also play a role in the antihypertensive mechanisms of garlic.

Antihypercholesterolaemic Antihyperlipidaemic Activity

In-Vitro Studies

Simultaneous feeding of garlic or onion unsaturated oil and high sucrose for 2 months counteracted the adverse effects of high sucrose in rats (Adamu et al. 1982). Along with a lipid-lowering effect, a modest but significant effect of tissue protein reduction was observed. The crude garlic was found to be more effective than petroleum ether and ethanol garlic extracts in inhibiting the rise of serum cholesterol level in cholesterol-fed rabbits (Rahmani et al. 1988). Ethanol was least effective in suppressing serum cholesterol concentration. Ajoene from garlic was found to be reactive towards sulfhydryl compounds and to inactivate human gastric lipase in-vitro (Gargouri et al. 1989). The results corroborated previous reports on the ability of garlic to lower triacylglycerol blood levels. Garlic-derived organosulfur compounds exerted differential inhibitory effects on cholesterol biosynthesis in primary rat hepatocyte cultures and may provoke multiple inhibition of this metabolic pathway in response to garlic consumption (Gebhardt and Beck 1996). Concerning early steps, allicin significantly inhibited incorporation of [^{14}C]acetate into non-saponifiable neutral lipids already at concentrations as low as 10 μM; diallyl disulfide and allyl mercaptan were effective above 100 μM only, and the two vinyldithiins started at 500 μM. If [^{14}C]acetate was replaced by [^{14}C]mevalonate, inhibition due to allicin, diallyl disulfide and allyl mercaptan disappeared suggesting that HMG-CoA reductase was the target of inhibition. Concerning the late step, the potency to exert accumulation of lanosterol presumably by inhibiting lanosterol 14 α-demethylase decreased in the order, allicin > diallyl disulfide > allyl mercaptan = 1,3-vinyldithiin > 1,2-vinyldithiin, the effect of the latter compound being close to zero. With respect to the total inhibition of [14C]acetate labelling of cholesterol, the half-maximal effective concentration value of allicin was determined to be 17 μM compared to 64 μM for diallyl disulfide and to 450 μM for allyl mercaptan. Garlic powdered extract significantly reduced the level of cholesteryl esters and free cholesterol in cultured cells and inhibited their proliferative activity after 24 hours incubation (Orekhov et al. 1995). In addition, the extract significantly reduced cholesterol accumulation and inhibited cell proliferation stimulated by blood serum taken from atherosclerotic patients. Blood serum taken 2 hours after an oral administration of 300 mg garlic powder tablet caused substantially less cholesterol accumulation in cultured cells. This suggested that garlic powder manifested direct antiatherogenic-related action not only in-vitro but also in-vivo. Studies by Slowing et al. (2001) suggested that administration of garlic fractions to rats fed with a high cholesterol could prevent diet-induced hypercholesterolaemia by plasma total cholesterol and LDL and vascular alterations in the endothelium-dependent relaxation associated with atherosclerosis.

Studies in rat primary hepatocyte cultures suggested that the hypocholesterolaemic effect of garlic could be attributed partly from decreased hepatic cholesterogenesis, whereas the triacylglycerol-lowering effect appeared to be due to the inhibition of fatty acid synthesis (Yeh and Yeh 1994). In further studies using cultured rat hepatocytes, Yeh and Liu (2001) found 44–87 % inhibition of cholesterol synthesis by the water-extractable fraction (WEF), methanol-extractable fraction (MEF) and petroleum ether-extractable fraction (PEF) of fresh garlic and Kyolic (liquid form of AGE). The results suggested that hydrophilic and hydrophobic compounds of garlic were inhibitory to cholesterol synthesis. Among water-soluble compounds, SAC, S-ethylcysteine (SEC) and S-propyl cysteine (SPC) inhibited cholesterol synthesis by 40–60 % compared with 20–35 % by gamma-glutamyl-S-allylcysteine (GSAC), gamma-glutamyl-S-methylcysteine (GSMC) and gamma-glutamyl-S-propyl cysteine (GSPC). Lipid-soluble sulfur compounds (i.e. diallyl sul-

fide, diallyl disulfide, diallyl trisulfide, dipropyl sulfide and dipropyl trisulfide) at low concentrations (0.05–0.5 mol/L) slightly (10–15 %) inhibited cholesterol synthesis but became highly cytotoxic at high concentrations (1.0–4.0 mol/L). All water-soluble compounds, except S-allylmercaptocysteine, were not cytotoxic, judging from the release of cellular lactate dehydrogenase (LDH) into the culture medium. The results suggested that cholesterol-lowering effects of garlic extract, such as aged garlic extract, emanated in part from inhibition of hepatic cholesterol synthesis by water-soluble sulfur compounds, especially SAC.

Among water-soluble compounds of garlic, *S*-allylcysteine (SAC), *S*-ethylcysteine (SEC) and *S*-propyl cysteine (SPC) inhibited [2-14C]acetate incorporation into cholesterol in a concentration-dependent manner, attaining 42–55 % maximal inhibition (Liu and Yeh 2000). γ-glutamyl-*S*-allyl cysteine, γ-glutamyl-*S*-methylcysteine and γ-glutamyl-*S*-propyl cysteine were less potent, exerting only 16–29 % maximal inhibitions. Alliin, *S*-allyl-*N*-acetyl cysteine, *S*-allylsulfonyl alanine and S-methylcysteine had no effect on cholesterol synthesis. Of the lipid-soluble compounds, diallyl disulfide (DADS), diallyl trisulfide (DATS) and dipropyl disulfide (DPDS) reduced cholesterol synthesis by 10–25 % at low concentrations (<or =0.5 mmol/L) and abrogated synthesis at high concentrations (>or =1.0 mmol/L). Diallyl sulfide, dipropyl sulfide and methyl allyl sulfide slightly inhibited [2-14C] acetate incorporation into cholesterol only at high concentrations. The complete suppression of cholesterol synthesis by DADS, DATS and DPDS was associated with cytotoxicity as indicated by a marked increase in cellular LDH release. There was no apparent increase in LDH secretion by water-soluble compounds except S-allyl mercaptocysteine, which also negated cholesterol synthesis. Based on maximal inhibition and IC_{50} (concentration required for 50 % of maximal inhibition) values, SAC, SEC and SPC were equally potent in inhibiting cholesterol synthesis. The results of subsequent studies indicated that SAC, SEC, SPC and gamma-glutamyl-S-methylcysteine inhibited lipid biosynthesis in cultured rat hepatocytes and further suggested that these S-alk(en)yl cysteines of garlic impaired triglyceride synthesis in part due to decreased de novo fatty acid synthesis resulting from inhibition on the lipogenic enzyme fatty acid synthase (Liu and Yeh 2001). Alliin, γ-glutamyl-*S*-allyl cysteine, γ-glutamyl-S-propyl cysteine, *S*-allyl-*N*-acetyl cysteine, *S*-allylsulfonyl alanine and *S*-methylcysteine had no effect on fatty acid synthesis. Further, *S*-allylcysteine (SAC), *S*-ethylcysteine (SEC) and *S*-propyl cysteine (SPC) inhibited cholesterol synthesis from [(14)C]acetate but not from [(14)C]mevalonate in cultured rat hepatocytes (Liu and Yeh 2002). The results suggested that *S*-alk(en)yl cysteines inhibited cholesterol synthesis by deactivating HMG-CoA reductase via enhanced phosphorylation, but not changing levels of mRNA or the amount of the enzyme. Additionally, of the three *S*-alk(en)yl cysteines tested, only SAC appeared to further decrease the activity of HMG-CoA reductase by increasing sulfhydryl oxidation of the enzyme. Diallyl trisulfide (DATS) inhibited the differentiation of 3T3-L1 preadipocytes into adipocytes (Lii et al. 2012). DATS prolonged ERK activation, which led to the downregulation of adipogenic transcription factor expression during adipogenesis. Their results suggested that garlic may have potential as an antiobesity agent. Khat (*Catha edulis*) and garlic in combination exhibited a synergistic effect in reducing the lipid contents of blood in-vitro (Abdul Aziz et al. 2010). The mechanism of garlic in reducing lipids could be explained by its emulsifying property, while the mechanism of khat by lipolysis.

Animal Studies

Allicin significantly reduced the lipid levels of serum and liver of normal rats on long-term (2 months) administration (Augusti and Mathew 1974). The effect of allicin was more pronounced in the liver than in the serum and was largely attributed to the decrease in the triglyceride level and free cholesterol. The increased levels of low-density lipoproteins (LDL) and LDL cholesterol in rats fed with the atherogenic diet were partly reversed in rats receiving a supplement of 2 %

garlic powder (Kamanna and Chandrasekhara 1982). On a cholesterol-containing diet, high-density lipoprotein (HDL) and HDL cholesterol levels were decreased. Inclusion of garlic powder in the atherogenic diet enhanced the percentage of HDL, whereas no change was observed in HDL cholesterol levels. Commercial garlic pearls (equivalent to 0.15 % garlic powder in the diet) also produced a significant decrease in serum and liver cholesterol levels in rats fed with the atherogenic diet. Feeding of garlic oil exerted hypolipidaemic effects in rats fed with ethanol and a high-fat high-cholesterol diet (Shoetan et al. 1984). Elevated levels of total lipids in the liver, and cholesterol and triglyceride in the serum, liver and kidneys were significantly reduced by garlic oil to levels near to those seen in untreated control rats. Cholesterol-induced hyperlipidaemia in male Sprague–Dawley rats was controlled by garlic feeding for 12 weeks (Chaudhuri et al. 1984). Garlic treatment did not alter the concentrations of circulating thyroid hormones and thyroidal uptake of radioiodine, suggesting that the hypolipidaemic effect of garlic was probably not mediated through the thyroid. Garlic oil extract administered with high-sucrose and high-alcohol diets significantly lowered the high levels of alkaline phosphatase and alcohol dehydrogenase in the serum, liver and kidneys in rats (Adoga and Osuji 1986). This effect was postulated to be due to the reduced biosynthesis of fatty acids as NADPH, required for the process, was utilised for the metabolism of the oil. Garlic ameliorated the signs associated with Cu deficiency, although hepatic lipogenesis was not affected (Fields et al. 1992). Administration of garlic reduced the activity of the lipogenic enzyme glucose-6-phosphate dehydrogenase only in Cu-adequate rats. Consumption of garlic resulted in increased epididymal fat pad and pancreas sizes and higher haematocrit, insulin and thyroxine concentrations. Both garlic protein (16 % of diet) and garlic oil (100 mg/kg body weight/day) exhibited significant lipid-lowering effects in hyperlipidaemic albino rats (Mathew et al. 1996). The hypolipidaemic action is primarily attributed to a decrease in hepatic cholesterogenesis in the treated rats. Even though garlic oil was found to be more effective, the garlic protein was more palatable and free from an obnoxious smell. Garlic protein (500 mg/kg body wt/day) given to rats exerted significant hypolipidaemic action comparable with a standard dose of gugu-lipid (Rajasree et al. 1999). The hypolipidaemic action was mainly due to an increase in cholesterol degradation to bile acids and neutral sterols and mobilisation of triacylglycerols in garlic-treated rats. Studies show that aqueous fresh garlic extract was beneficial in reducing blood cholesterol, triglyceride levels and systolic blood pressure in hypercholesterolaemic rats (Ali et al. 2000a). The results showed that garlic may beneficially affect two risk factors for atherosclerosis – hyperlipidaemia and hypertension.

Garlic treatment reduced significantly total cholesterol, LDL cholesterol and triglycerides, but not HDL cholesterol in rats with chronic nephrotic syndrome induced by puromycin aminonucleoside (Pedraza-Chaverrí et al. 2000). Garlic treatment was unable to modify proteinuria in either acute or chronic nephrotic syndrome. Garlic induced no change in the percentage of sclerotic glomeruli in chronic nephrotic syndrome but decreased significantly the percentage of sclerotic area of these glomeruli. The data indicated that garlic treatment ameliorated hyperlipidaemia and renal damage in chronic nephrotic syndrome which was unrelated to proteinuria or antioxidant enzymes.

Hypercholesterolaemia in rats induced by cholesterol feeding was significantly reduced by garlic (Aouadi et al. 2000). Garlic supplementation increased high-density lipoprotein and decreased low-density lipoprotein in normal and hypercholesterolaemic rats. The reduction in the plasma cholesterol by feeding garlic was in low-density lipoprotein and very-low-density lipoprotein cholesterol fractions. Feeding garlic diet decreased liver weight. Saponin fractions from garlic lowered plasma total and LDL cholesterol concentrations without changing HDL cholesterol levels in a hypercholesterolaemic animal model (Matsuura 2001). In-vivo studies in rats suggested that long-term dietary supplementation of fresh garlic may exert a lipid-lowering effect partly through reducing intestinal MTP

mRNA gene expression, thus, suppressing the assembly and secretion of chylomicrons from the intestine to the blood circulation (Lin et al. 2002). In-vitro, fresh garlic extract reduced MTP mRNA levels in both the human hepatoma HepG2 and intestinal carcinoma Caco-2 cells in a dose-dependent fashion.

Durak et al. (2002) demonstrated that cholesterol supplementation in rabbits led to dense plaque formation in the aortas of the rabbits, while garlic extract supplementation ameliorated blood lipid profile increased antioxidant potential and could significantly reduce plaque surface area in the aorta. Aqueous garlic extract exerted a significant effect on lowering the Triton WR-1339-induced cholesterol and triglyceride in the rat's blood (Sarwar et al. 2005). The hypocholesterolaemic and hypotriglyceridaemic effect of garlic extract was higher than the reference compound nicotinamide, a well-known hypocholesterolaemic and hypotriglyceridaemic compound. In rats rendered hyperlipidaemic by maintaining them on a high-fat diet (30 %) for 8 weeks, incorporation of curcumin (0.2 %) or capsaicin (0.015 %) or garlic (2.0 %) in the diet produced significant hypotriglyceridaemic effect. Plasma cholesterol remained unaffected in high-fat treatment (Kempaiah and Srinivasan 2006). Elevated hepatic triglyceride content in high-fat-fed rats was significantly lowered by the three spices. The altered osmotic fragility of erythrocytes and the reduction in Ca(2+),Mg(2+)-ATPase activity in the erythrocyte membrane in the high-fat-fed rats were all corrected by the three dietary spices. Gorinstein et al. (2006a) found that dietary supplementation of raw and boiled garlic enhanced plasma antioxidant activity and improved plasma lipid metabolism in cholesterol-fed rats. Garlic boiled for 20 minutes had the same bioactivity as raw garlic in its antioxidant and protein spectra. The selenium and copper content of raw garlic was not altered by boiling.

Simultaneous feeding of garlic protein (GP) or soy protein (SP) (500 mg/kg body weight/day for 45 days) to alcohol-fed rats increased the alcohol-lowered antioxidant enzymes, lecithin cholesterol acyltransferase (LCAT) in plasma, levels of HDL cholesterol in serum, hepatic bile acid production and faecal excretion of neutral sterols (Rajasree et al. 2009). Increase in glutathione content and catalase activity in the liver was significantly higher for the SP-treated group than for the GP-treated group. However, increase in plasma LCAT was significantly higher for the GP-treated group than for the SP-treated group. GP- and SP-treated rats reverted the alcohol-elevated lipid profile and activity of HMG-CoA reductase in the liver and intestine; lipid peroxidation, glucose-6-phosphate dehydrogenase (G6PD), glutathione peroxidase (GPx) and glutathione reductase (GR) in the liver; and incorporation of labelled acetate into liver cholesterol back towards normal. GP feeding showed a better effect than SP in lowering serum and heart total cholesterol, and in maintaining GPx at near normal level, while SP feeding showed a better effect in lowering serum FFA level and maintaining GR activity at near normal level. In suppressing the incorporation of labelled acetate into serum cholesterol, GP feeding showed a better effect than SP. Antiatherogenic and antiperoxidative effects of these proteins may be due to lower lysine/arginine ratio.

Studies showed that garlic significantly reduced total cholesterol (TC), plasma triglyceride (TG), LDL-C, VLDL-C, liver triglyceride, plasma malondialdehyde (MDA) and elevated plasma antioxidant in garlic-treated rats compared to rats fed on a lipogenic diet containing sunflower oil, cholesterol and ethanol only (Heidarian et al. 2011). Also, liver phosphatidate phosphohydrolase activity was decreased in rats fed with garlic and a standard diet. Administration of garlic significantly reduced high-fat diet (HFD)-induced body weight, epididymal fat accumulation, hyperlipidaemia and hypercholesterolaemia in mice (Kim and Kim 2011). Consequently, the atherogenic indices were reduced by 83 % and 91 %, respectively, in the 2 % and 4 % garlic-supplemented group. Liver steatosis induced by HFD was ameliorated by garlic supplementation. Additionally, garlic affected the downregulation of expression patterns of epididymal adipose tissue genes such as peroxisome proliferator-activated receptor γ (PPARγ), acetyl-CoA carboxylase (ACC),

adipose-specific fatty acid-binding protein (aP2) and glycerol-3-phosphate dehydrogenase (GPDH). The results suggested that garlic may have a potential benefit in preventing obesity. Oral administration of thiacremonone, from garlic, for 3 weeks to db/db mice elicited a loss of body weight and decrease in blood triglyceride and glucose levels compared with the control mice (Ban et al. 2012). Histological analysis further revealed that thiacremonone significantly decreased lipid accumulation in the fatty livers of treated db/db mice. GLUT4 expression and glucose uptake were upregulated by thiacremonone in 3T3-L1 adipocytes. Thiacremonone treatment also suppressed expression levels of acetyl-CoA carboxylase (ACC) and fatty acid synthase (FAS) involved in lipid metabolism, in the liver of db/db mice. Additionally, thiacremonone enhanced the peroxisome proliferator-activated receptor γ (PPARγ) expression in the fatty liver. Other studies found that supplementation with methanolic extract of black garlic (MEBG) decreased the final body weight, relative masses of the liver and fat tissues, serum triacylglyceride levels and hepatic oxidative stress and increased the faecal lipid contents in high-fat diet (HFD) rats (Chen et al. 2014b). It was found that supplementation with MEBG ameliorated diet-induced obesity via regulating adipogenesis, adipokine biosynthesis and lipolysis. The results suggested that MEBG could be developed as a potential nutraceutical ingredient for the prevention of obesity. Compared with hypercholesterolaemic mice, treatment with garlic extract significantly decreased total cholesterol, low-density lipoprotein cholesterol (LDL-C), triglycerides, very-low-density lipoprotein-cholesterol (VLDL-C), atherogenic index, alanine aminotransferase (ALT) and aspartate aminotransferase (AST) (Mohammadi and Oshaghi 2014). Change in HDL-C levels was not significant in garlic extract-treated animals compared with the hypercholesterolaemic group. Liver X receptor protein α and mRNA in the intestine were increased in the garlic extract-treated group compared with the chow group, while in the liver, only the mRNA of liver X receptor α was increased in the hypercholesterolaemic control mice.

Diallyl disulfide (DADS) analogues were effective in reducing the total lipid levels which could be correlated with a significant decrease in 3-hydroxy-3-methylglutaryl-CoA reductase (HMGR) activity (Rai et al. 2009). DADS analogues strongly inhibited HMGR activity in-vivo in Wistar rats but not in-vitro. These results could be attributed to the significant decrease in the mRNA levels and protein expression of HMGR. Further, DADS analogues significantly inhibited the activation of sterol regulatory element-binding protein-2 (SREBP-2) and interfered with the DNA binding activity of cAMP response element-binding protein (CREB) but not nuclear factor-Y (NF-Y), with upstream regulatory sequences of HMGR. DADS analogues were also effective in reducing the levels of oxidised low-density lipoprotein (ox-LDL), lipid peroxidation as well as NF-κB activity, showing good anti-inflammatory and antioxidant properties.

Clinical Studies

Studies on human subjects found that on a fat-rich diet, the serum cholesterol, serum triglycerides and serum total lipids were significantly increased as compared to normally fed diet for 2 weeks (Bakhsh and Chughtai 1984). When 40 g of garlic was substituted in fat-rich diet for 7 days, garlic significantly reduced the serum cholesterol and serum triglycerides. In a study of 20 patients with hyperlipoproteinaemia over a period of 4 weeks, intake of dried garlic significantly decreased fibrinogen and fibrinopeptide A by 10 % (Harenberg et al. 1988). Streptokinase-activated plasminogen and fibrinopeptide B beta 15–42 were significantly increased by about 10 %. Serum cholesterol levels significantly decreased by 10 %. Systolic and diastolic blood pressure decreased. ADP- and collagen-induced platelet aggregation was not affected. Evidence from the German Association of General Practitioners' multi-centric placebo-controlled double-blind study involving a total of 261 patients of 30 general practitioners in West Germany showed that intake of standardised garlic tablets for 16 weeks was effective in the treatment of hyperlipidaemia by lowering total

cholesterol values by an average of 12 % and triglyceride values by an average of 17 % (Mader 1990a, b). In a double-blind study of 40 hypercholesterolaemic outpatients, the group-administered 900 mg garlic powder per day (equivalent to 2,700 mg of fresh) for 4 months showed significantly lower total cholesterol, triglycerides and blood pressure than those of the placebo group (Vorberg and Schneider 1990). In addition, results of a self-evaluation questionnaire indicated that patients in the drug group had a greater feeling of 'well-being'.

In a randomised, double-blind, placebo-controlled study of 42 healthy adults, it was found that treatment with standardised garlic 900 mg/day produced a significantly greater reduction in serum total cholesterol and LDL-C than placebo (Jain et al. 1993). There were no significant changes in high-density lipoprotein cholesterol, triglycerides, serum glucose, blood pressure and other monitored parameters. The garlic formulation was well tolerated without any odour problems. In a double-blind, placebo-controlled, randomised crossover study of subjects with mild to moderate hypercholesterolaemia, Simons et al. (1995) found no demonstrable effect of garlic ingestion on lipids and lipoproteins. Comparing the period on garlic with that on the placebo, there were no significant differences in plasma cholesterol, LDL cholesterol, HDL cholesterol, plasma triglycerides, lipoprotein(a) concentrations or blood pressure. There was no demonstrable effect of garlic on the oxidisability of LDL, on the ratio of plasma lathosterol/cholesterol (a measure of cholesterol synthesis) nor on the LDL receptor expression in lymphocytes.

In another double-blind crossover study of 41 moderately hypercholesterolaemic men, dietary supplementation with aged garlic extract had beneficial effects on the lipid profile and blood pressure (Steiner et al. 1996). The major findings were a maximal reduction in the total serum cholesterol of 6.1 % or 7.0 % in comparison with the average concentration during the placebo administration or baseline evaluation period, respectively. Low-density lipoprotein cholesterol was also decreased by aged garlic extract, 4 % when compared with average baseline values and 4.6 % in comparison with placebo period concentrations. In addition, there was a 5.5 % decrease in systolic blood pressure and a modest reduction of diastolic blood pressure in response to aged garlic extract. In a double-blind, randomised 6-month parallel trial involving 115 individuals with a repeat total cholesterol concentration of 6.0–8.5 mmol/L and low-density lipoprotein (LDL) cholesterol of 3.5 mmol/L or above after 6 weeks of dietary advice, garlic was less effective in reducing total cholesterol than suggested by the meta-analyses (Neil et al. 1996). There were no significant differences between the groups receiving garlic and placebo in the mean concentrations of serum lipids, lipoproteins or apo A1 or B. In a meta-analysis which included the results from this trial, garlic was associated with a mean reduction in the total cholesterol of –0.65 mmol/L.

Yeh et al. (1997) showed that aged garlic extract (AGE) supplementation was effective in lowering the plasma concentration of total cholesterol by 7 % and LDL cholesterol by 10 % in hypercholesterolaemic men compared with subjects consuming a placebo. Yeh et al. (1997) showed that aged garlic extract (AGE) supplementation was effective in lowering the plasma concentration of total cholesterol by 7 % and LDL cholesterol by 10 % in hypercholesterolaemic men compared with subjects consuming a placebo. Gardner et al. (2007) found no statistically or clinically significant effects on LDL-C or other plasma lipid concentrations in adults with moderate hypercholesterolaemia when given raw garlic, powdered garlic supplement and aged garlic extract supplement at an approximate dose of a 4 g clove per day, 6 day/week for 6 months. In a single-blind, placebo-controlled study of 150 hyperlipidaemic patients, supplementation of coated garlic powder tablet (equal to 400 mg garlic, 1 mg allicin) twice daily for 6 weeks decreased total cholesterol and LDL cholesterol but increased HDL cholesterol (Kojuri et al. 2007).

Intake of *Monascus pilosus* garlic-fermented extract (MGFE) containing characteristic compounds such as dimerumic acid and monacolin, by hyperlipidaemic subjects, significantly

reduced serum total cholesterol (TC) and low-density lipoprotein cholesterol levels 2 and 4 weeks after the start of MGFE intake as compared with the baseline (Sumioka et al. 2006). Although the level of high-density lipoprotein cholesterol (HDL-C) was unaffected at any time, the atherogenic index calculated from the value of total cholesterol and HDL-C was significantly reduced 2 and 4 weeks after the start of MGFE intake. In a more recent randomised, double-blind, placebo-controlled, parallel-group trial, the intake of MGFE for 12 weeks decreased triglyceride and cholesterol in serum with no appreciable adverse effects in normal to mildly hyperlipidaemic individuals, suggesting that it may be effective to improve and prevent the metabolic syndrome (Higashikawa et al. 2012). In a recent double-blind, randomised, placebo-controlled trial involving patients with mild hypercholesterolaemia (28 aged black garlic administered, 22 placebo treated), aged black garlic (ABG) supplementation reduced atherogenic markers and thus may have a cardioprotective effect beyond the gold standard medication (Jung et al. 2014). ABG increased high-density lipoprotein cholesterol levels compared with the placebo group at the end of the study. Moreover, a significant decrease in the levels of apolipoprotein B and a significant increase in the ratio of low-density lipoprotein cholesterol/apolipoprotein B were observed in the ABG group. No adverse effects were reported in any of the patients.

In a double-blind, randomised, placebo-controlled trial of 25 patients (mean age, 58 years) with moderate hypercholesterolaemia, commercial garlic oil preparation administered for 12 weeks had no influence on serum lipoproteins, cholesterol absorption or cholesterol synthesis (Berthold et al. 1998). In a multi-centre, randomised, placebo-controlled trial involving patients with hypercholesterolaemia (28 garlic treated, 22 placebo treated), garlic powder (900 mg/day) treatment for 12 weeks was ineffective in lowering cholesterol levels (Isaacsohn et al. 1998). The pilot study of moderately hypercholesterolaemic volunteers by Byrne et al. (1999) did not support the hypothesis that dietary garlic supplementation decreased the susceptibility of isolated LDL to oxidation and that patterns of LDL fractions in plasma might be involved. Levels of lipoprotein(a) in plasma were also not changed. Other mechanisms of cardiovascular benefit were however not excluded. In a double-blind, randomised, placebo-controlled trial of fifty moderately hypercholesterolaemic subjects, garlic treatment for 3 months resulted in no significant change in total cholesterol, LDL cholesterol, HDL cholesterol, HDL subclass distribution, postprandial triglycerides, apolipoprotein B, lipoprotein (a) (Lp[a]), LDL peak particle diameter or LDL subclass distribution (Superko and Krauss 2000). Garlic may have a greater effect on LDL particle diameter in LDL pattern A compared with pattern B subjects. This difference was not selected in other lipid measurements. In a 16-week prospective double-blind placebo-controlled study of 33 adult patients (13 garlic, 20 placebo) with primary hypercholesterolaemia, administration of garlic in the form of alliin 22.4 mg/day did not affect either lipid levels or various psychopathologic parameters (Peleg et al. 2003).

Review/Meta-analysis Studies

Meta-analysis of the controlled trials of garlic to reduce hypercholesterolaemia showed a significant reduction in total cholesterol levels (Warshafsky et al. 1993). The best available evidence suggested that garlic, in an amount approximating one half to one clove per day, decreased total serum cholesterol levels by about 9 % in the groups of patients studied. In the systematic review and meta-analysis conducted by Silagy and Neil (1994b), garlic therapy elicited a 12 % reduction in total cholesterol level compared with placebo. The reduction was evident after 1 month of therapy and persisted for at least 6 months. In the dried garlic powders, in which the allicin content was standardised, there was no significant difference in the size of the reduction across the dose range of 600–900 mg daily. Dried garlic powder preparations also significantly lowered serum triglyceride compared to placebo. The meta-analysis of 13 randomised, double-blind, placebo-controlled trials conducted by Stevinson

et al. (2000) suggested garlic to be superior to placebo in reducing total cholesterol levels. However, the size of the effect was modest, and the robustness of the effect was debatable. The meta-analysis conducted by Ackermann et al. (2001) that covered 1,798 pertinent records, 45 randomised trials (4 weeks or more) and 73 additional studies reporting adverse events found that compared with placebo, garlic preparations may lead to small reductions in the total cholesterol level at 1 and 3 months but not 6 months. Changes in low-density lipoprotein levels and triglyceride levels paralleled total cholesterol level results; no statistically significant changes in high-density lipoprotein levels were observed. Trials also reported significant reductions in platelet aggregation and mixed effects on blood pressure outcomes. No effects on glycemic-related outcomes were found. Proven adverse effects included malodorous breath and body odour. Other unproven effects included flatulence, oesophageal and abdominal pain, allergic reactions and bleeding.

In the meta-analysis conducted by Khoo and Aziz (2009) that involved 13 trials and 1,056 subjects, the available evidence from the randomised controlled trial did not demonstrate any beneficial effects of garlic on serum cholesterol.

Antiatherosclerotic Activity

In-Vitro Studies

Incubation of primary human coronary artery endothelial cell with garlic extract significantly decreased intercellular adhesion molecule-1 (ICAM-1, CD54) and vascular cell adhesion molecule-1 (VCAM-1, CD 106) expression induced by interleukin IL-1α (Rassoul et al. 2006). In addition the presence of garlic extract significantly inhibited the adhesion of monocytes to interleukin IL-1α-stimulated endothelial cells. The results indicated that garlic extract modulated the expression of ICAM-1 and VCAM-1, thus potentially contributing to the beneficial antiatherogenic effects traditionally attributed to garlic. Aged garlic extract (AGE) inhibited Ox-LDL-induced peroxides in bovine pulmonary artery endothelial cells, suppressed peroxides in murine macrophage (J774 cells) dose dependently and also inhibited NO production in J774 cells (Ide and Lau 1999). Pretreatment with AGE reverted the increase of LDH release and depletion of GSH caused by oxidised LDL. In a cell-free system, AGE was shown to scavenge H_2O_2 dose dependently. The data suggested AGE to be a useful protective agent against cytotoxicity associated with Ox-LDL and NO, and it may thus be useful for the prevention of atherosclerosis and cardiovascular diseases. Alcoholic garlic extract increased the ATP-binding cassette transporter A1 (mRNA (20–23 %) and protein expression (18–37 %) in THP-1 macrophage cells compared with the controls (untreated cells) (Malekpour-Dehkordi et al. 2011). The results indicated the possibility of using alcoholic garlic extract to promote reverse cholesterol efflux in macrophages and prevent atherosclerosis. Yamaji et al. (2004) found that egg yolk-enriched garlic powder (EGP) inhibited copper-induced LDL oxidation in a dose-dependent manner. They observed that pretreatment of EGP significantly suppressed the production of peroxides in HL60 cells and protected endothelial cells from hydrogen peroxide-induced cell injury. These findings suggested that EGP might be useful in the prevention of atherosclerosis.

Cell counting, DNA synthesis and cell cycle analysis showed that ajoene, at 1–50 μM, interfered with the progression of the G1 phase of the cell cycle and inhibited rat smooth muscle cell (SMC) proliferation (Ferri et al. 2003). Additionally, ajoene was shown to inhibit cholesterol biosynthesis by affecting 3-hydroxy-3-methyl-glutaryl coenzyme A (HMG-CoA) reductase and late enzymatic steps of the mevalonate (MVA) pathway. Labelling of smooth muscle cell cellular proteins with farnesol (FOH) and geranylgeraniol (GGOH) was significantly inhibited by ajoene. In-vitro assays for protein farnesyltransferase (PFTase) and protein geranylgeranyltransferase type I (PGGTase-I) confirmed that ajoene inhibited protein prenylation. Ajoene interference with the protein prenylation reaction may contribute to its inhibition of SMC proliferation. Diallyl trisulfide (DAT), a natural

organosulfur compound in garlic, protected vascular endothelium impairments from high-glucose-induced or hyperglycaemia-induced injury in endothelial cells in-vitro and in-vivo in obese diabetic rats by reducing mitochondrial oxidative stress and considerably improved mitochondrial respiration function (Liu et al. 2014). The findings provided a novel insight for DAT to potentially treat the oxidative stress diseases, i.e. atherosclerosis, diabetes and neurodegenerative diseases.

Animal Studies

Bordia et al. (1975a) found that the marked rise in serum cholesterol and blood coagulability that followed 3 months of cholesterol feeding (0.2 g/kg/day) was significantly reduced by the essential oils of both onion and garlic in rabbits. Fibrinolytic activity was actually increased even above the normal control levels. The essential oils of onion and garlic (equivalent to 1 g/kg/day of raw bulbs) proved more effective than clofibrate in the usual clinical dose of 33 mg/kg/day. Garlic was even more effective than onion. Addition of cholesterol in the diet of male albino rabbits produced hypercholesterolaemia, increased tissue cholesterol and atheromatous changes in the aorta, but supplementation of garlic oil along with cholesterol significantly inhibited the hypercholesterolaemia and decreased tissue cholesterol and minimised the atheromatous changes in the aorta (Jain and Konar 1978). The results indicated that the active constituent(s) in garlic responsible for its antiatherogenic action was present in the oily fraction of garlic.

Garlic supplementation to cholesterol-rich diet retarded the development of atherosclerosis in rabbits as indicated by biochemical and histological studies (Mirhadi et al. 1991). Oral administration of petroleum ether extract of *Allium sativum*, in albino rats, significantly prevented rise in serum cholesterol and serum triglyceride level, caused by atherogenic diet (Lata et al. 1991). It also conferred significant protection against atherogenic diet-induced atherosclerosis. Two bioactive garlic compounds, ajoene (IC_{50} 2.5–5 μM) and allicin (IC_{50} 15–20 μM), dose dependently reduced nitrite accumulation, a parameter for NO synthesis, in supernatants of lipopolysaccharide (LPS)-stimulated RAW 264.7 macrophages (Dirsch et al. 1998). Both compounds markedly reduced inducible nitric oxide synthase (iNOS) protein as well as mRNA levels. iNOS had recently been shown to be present in human atherosclerotic lesions and to promote the formation of deleterious peroxynitrite. Both allicin and ajoene could contribute to the beneficial effects of garlic in atherosclerosis. Garlic protein diet or daily administration of garlic oil to 2 % cholesterol-fed rats controlled significantly the increases in sulfated glycosaminoglycans in their heart and aorta (Mathew and Augusti 1996). However hyaluronic acid level increased, uridine diphosphoglucose dehydrogenase decreased and several degrading enzymes increased in the aorta on garlic treatment. The effects of garlic treatment were just the reverse in the liver.

The hypercholesterolaemic diet of rabbits caused an increase in aortic arch cholesterol (2.1 mg cholesterol/g tissue) which was significantly reduced by aged garlic extract 'Kyolic' supplementation (1.7 mg cholesterol/g tissue) (Efendy et al. 1997). 'Kyolic' significantly inhibited the development of thickened, lipid-filled lesions in the preformed neointimas produced by balloon catheter injury of the right carotid artery in cholesterol-fed rabbits but had little effect in rabbits on a standard diet. In-vitro studies showed that 'Kyolic' had a direct effect on the inhibition of smooth muscle proliferation. The data showed that 'Kyolic' treatment reduced the fatty streak development, vessel wall cholesterol accumulation and development of fibrofatty plaques in the neointimas of cholesterol-fed rabbits, thus providing protection against the onset of atherosclerosis.

On incorporation of 5 % garlic, amla or onion separately in the animal fat (butter fat, beef) diets to albino rats for 3 months, each of them ameliorated the deleterious effects of the animal fats (Augusti et al. 2001a). Butter fat was found to be more atherogenic than beef. The order of the ameliorative effects of the vegetables was garlic > amla > onion. The better hypolipidaemic effects and correction of elevated levels of certain enzymes shown by garlic and amla may be due to

the facts that they contained comparatively better active principles than that found in onions. When 5 % garlic was incorporated with any of the high-fat diets containing 40 % by weight of coconut kernel or groundnut with and without 2 % cholesterol, the lipid parameters, their peroxidation and alterations in enzyme activities in serum and tissues of rats were significantly decreased (Augusti et al. 2001b). The results showed that garlic contained some principles that counteracted the atherogenicity of the above oil seeds. Further they (Augusti et al. 2005) found that feeding rats with a polar fraction of garlic oil at a dosage of 100 mg/kg along with diets containing 20 % of sesame oil or coconut oil along with 2 % cholesterol for 2 months counteracted significantly the hyperlipidaemic, oxidant and also most of the other deleterious effects of the oils like raised lipid levels in serum and tissues, raised serum levels of AST and tissue levels of HMG-CoA reductase and the lowered serum and tissue levels of glutathione reductase. The results supported the claims that ajoene, the major polar compound of garlic oil, had very good biological action. In-vivo studies showed that daily dietary supplementation of allicin reduced the atherosclerotic plaque area by 68.9 and 56.8 % in apolipoprotein E-deficient and low-density lipoprotein (LDL) receptor knockout mice, respectively, as compared with the control mice (Gonen et al. 2005). LDL isolated from allicin-treated groups was more resistant to CuSO(4)-induced oxidation ex *vivo* than LDL isolated from the control mice. They also demonstrated reduced Cu(2+) binding to LDL following allicin treatment. LDL treatment with allicin significantly inhibited both native LDL and oxidised LDL degradation by isolated mouse macrophages. A notable restoration of arterial blood pressure was seen in rats on garlic- and turmeric-supplemented diet (Zahid Ashraf et al. 2005). Animals on supplemented diet showed a significantly enhanced vasorelaxant response to adenosine, acetylcholine and isoproterenol, and contractile effect of 5-hydroxytryptamine was significantly attenuated. The present study demonstrated that garlic and turmeric were potent vasorelaxants and possessed antiatherogenic properties in reducing cholesterol.

Studies in albino rats showed that moderate and high doses of garlic homogenate possessed potential antiatherosclerotic property that was significantly attenuated by propranolol (PRO) and hydrochlorothiazide (HYD) (Asdaq et al. 2009). However, garlic homogenate antihyperlipidaemic activity was augmented by captopril (CAP). It was concluded that administration of PRO and HYD decreased the hypolipidaemic effect of garlic homogenate and administration of garlic homogenate along with CAP augmented the hypolipidaemic effect of garlic homogenate. Espirito Santo et al. (2004) found that dietary supplementation of APOE*3-Leiden transgenic mice with the garlic formulation Printanor or garlic Kyolic (fermented garlic) for 28 weeks did not produce hypolipidaemic, anti-inflammatory or antiatherosclerotic properties.

Clinical Studies

In a study of ten healthy subjects, garlic and onion administered randomly on four different days during a 1-week period exerted a significant protective action against fat-induced increases in serum cholesterol and plasma fibrinogen and decreases in coagulation time and fibrinolytic activity (Bordia et al. 1975b). The essential oil fraction, which contains all the taste and odour, exactly duplicated the beneficial effects of whole garlic and onion. Results of a study suggested that the addition of garlic in the diet of six male subjects for 3 weeks resulted in significantly lower levels in serum triglyceride and an increase in fibrinolytic activity of blood at the end of the second and third weeks (Jain 1977). The levels of total serum cholesterol and β-lipoprotein cholesterol when compared with the initial values were lower at the end of the first, second and third weeks. However, whole blood coagulation time did not show any alteration after the addition of garlic. In a study of males of the age group of 18–35, daily ingestion of 10 g garlic for 2 months caused a significant decrease in blood cholesterol levels (Bhushan et al. 1979).

An increase in plasma cholesterol and fibrinogen and a decrease in blood fibrinolytic activity (BFA) were observed during alimentary lipaemia produced by an ingestion of a fatty breakfast by healthy volunteers (Sharma et al. 1978). Addition

of garlic in its both raw and boiled forms to fatty breakfast was found to prevent the rise in cholesterol and fibrinogen in blood and to produce an enhancement of BFA. Fibrinolytic enhancing effect of garlic appeared to be mediated through an increase in the blood activator of fibrinolysis. A decrease in blood cholesterol may also contribute to this action indirectly as increased concentration of this lipid was found to decrease the BFA.

A weak clinical efficacy of a 12-week therapy with garlic powder (daily dose, 800 mg) was demonstrated in patients with peripheral arterial occlusive disease stage II (Kiesewetter et al. 1993a). The increase in walking distance in the garlic group by 46 m (from 161.0 to 207.1 m) was significantly higher than in the placebo group (by 31 m, from 172.0 to 203.1). The diastolic blood pressure, spontaneous thrombocyte aggregation, plasma viscosity and cholesterol concentration also decreased significantly in the garlic group (Kiesewetter et al. 1991). Body weight was maintained. In a 2-week, placebo-controlled, randomised, double-blind crossover trial of ten healthy volunteers receiving 600 mg/day of garlic powder, Phelps and Harris (1993) found that although serum lipid and lipoprotein levels were not lowered in this short time period, the ex-vivo susceptibility of apolipoprotein B-containing lipoproteins to oxidation was significantly decreased (−34 %). Garlic had been reported to beneficially affect serum lipid levels, platelet function, fibrinolysis and blood pressure, and this additional effect of retarding lipoprotein oxidation may contribute to the potential antiatherosclerotic effect of garlic.

In a cross-sectional observational study of healthy elderly adults ($n = 101$; age, 50–80 years), chronic garlic powder intake was found to attenuate age-related increases in aortic stiffness (Breithaupt-Grögler et al. 1997). The data strongly supported the hypothesis that garlic intake had a protective effect on the elastic properties of the aorta related to ageing in humans. In a single-blind, placebo-controlled crossover study of 40 consecutive subjects with lipid profile abnormalities, the combination of fish oil and garlic oil caused favourable shifts in the lipid subfractions within 1 month (Morcos 1997). Triglycerides were affected to the largest extent. The cholesterol lowering and improvement in lipid/HDL risk ratios suggested that these combinations may have antiatherosclerotic properties and may protect against the development of coronary artery disease. In a 1-year, placebo-controlled, double-blind, randomised pilot study, where 19 patients completed the study, administration of aged garlic extract was found to inhibit the rate of progression of coronary arterial calcification in atherosclerosis, as compared to placebo (Budoff et al. 2004). Lau (2006) reported that in a double-blind, placebo-controlled, crossover study involving 20 subjects (10 men and 10 women; mean age, 64 years), short-term supplementation of garlic demonstrated an increased resistance of LDL to oxidation. He also reported that aged garlic extract and its constituents SAC and allixin also suppressed LDL oxidation in-vitro. Oxidation of LDL had recently been recognised as playing an important role in the initiation and progression of atherosclerosis.

In a study of 112 patients (40–60 years old) with atherogenic dislipoproteidemy, 6 months therapy of garlic Allicor tablets resulted in a moderate hypolipidaemic and antioxidative effect (Gromnatskiĭ et al. 2007). They reported that a dosage of 600 mg per day decreases individual 10-year chance of fatal cardiovascular complications at patients with clinical signs of atherosclerosis, whereas for patients with no signs of atherosclerosis, the complications decrease with dosage of 300 mg per day.

In a placebo-controlled, double-blind, randomised trial of 65 intermediate risk firefighters (age 55 ± 6 years), daily treatment of a capsule containing aged garlic extract (1,200 mg) and coenzyme Q10 (120 mg) for a year was found to have beneficial effects on inflammatory markers and reduced progression of coronary atherosclerosis compared to the placebo-treated group (Zeb et al. 2012).

Hypotensive/Antihypertensive Activity

In-Vitro Studies

Garlic and garlic-derived bioactives possessed significant medicinal properties with the potential for ameliorating hypertension and associated

morbidity (Shouk et al. 2014). They recently reviewed the role of garlic bioactives, S-allylcysteine and allicin, in modulating various parameters such as oxidative stress, nitric oxide bioavailability, hydrogen sulfide production, angiotensin-converting enzyme activity, expression of nuclear factor-κB and the proliferation of vascular smooth muscle cells implicated in the pathogenesis of hypertension. Garlic organosulfur compounds S-allylcysteine, alliin and diallyl sulfides had no effect on epithelial sodium channel (ENaC) (Krumm et al. 2012). By contrast, the thiol-reactive garlic compound allicin significantly inhibited ENaC to a similar extent as garlic extract. Dysregulated activity of ENaC had been reported to be associated with human diseases such as hypertension, the salt-wasting syndrome pseudohypoaldosteronism type 1, cystic fibrosis, pulmonary oedema or intestinal disorders.

Garlic caused dose-dependent relaxations in isolated rat aorta which were attenuated by the removal of endothelium as in the case of acetylcholine (Öztürk et al. 1994). The vasorelaxant effects of acetylcholine and garlic revealed that the mechanism(s) of the effect of garlic may be different from that of acetylcholine. The findings obtained strongly suggested that the vasorelaxant effect of garlic was important in its hypotensive activity and mediated by the production of endothelium- and/or muscle-derived relaxing factors. Studies showed that the single dose of garlic used had a maximum antihypertensive effect 2–6 hours after oral administration to 2K-1C rats (Al-Qattan et al. 1999). The multiple dose of garlic appeared to be effective in restraining the expected rise in blood pressure that normally occurred in 2K-1C rats. The study suggested that garlic possessed an effective antihypertensive ability and may be used as a supplementary and natural remedy in cases of unilateral renovascular hypertension.

Fractions of garlic aqueous extract with high angiotensin I-converting enzyme (ACE) inhibitory activity yielded seven dipeptides with ACE inhibitory properties (Suetsuna 1998). These dipeptides were identified as Ser–Tyr, Gly–Tyr, Phe–Tyr, Asn–Tyr, Ser–Phe, Gly–Phe and Asn–Phe, with IC_{50} (the amount of peptide needed to inhibit ACE activity) values of 66.3, 72.1, 3.74, 32.6, 130.2, 277.9 and 46.3 μM, respectively. The presence of these dipeptides in garlic suggested that these compounds may, at least in part, be responsible for the observed antihypertensive effect of garlic (or garlic extracts) in animals and humans. Further, long-term use of dietary garlic may have a protective effect against rise in blood pressure.

Castro et al. (2010) demonstrated that allyl methyl sulfide (AMS) and diallyl sulfide (DAS) inhibited aortic smooth muscle cell angiotensin II-stimulated cell cycle progression and migration. Their inhibitory effects were associated to the prevention of the cell cycle inhibitor p27(Kip1) (p27) downregulation and the reduction of extracellular signal-regulated kinase 1/2 phosphorylation. Also, both organosulfur compounds inhibited angiotensin II-reactive oxygen species generation. The results showed that AMS and DAS could be effective antioxidants targeted at the arterial remodelling seen in hypertension.

Animal Studies

It was found that garlic extract exhibited a hypotensive effect only in-vivo, while both in-vivo and in-vitro, it exerted a hypocalcaemic effect (Song et al. 1963b). Garlic hypotensive effect in atropinised rabbits and in ganglionic blocked rabbits (hexamethonium) was the same as the effect found in rabbits which had not been drugged. Epinephrine also did not change the hypotensive effect of garlic. The hypocalcaemic effect of garlic extract was due to the combining of garlic with blood calcium, and the muscular activity may be secondary to hypocalcaemia.

Allicin, (1, 2.5 or 10 μg), topically applied, but not the precursor, alliin (10 μg), lowered intraocular pressure unilaterally in normal rabbits, but no change occurred in sympathectomised rabbit eyes (Chu et al. 1993). Moreover, allicin (0.01, 0.1 or 1 μM) caused 40, 40 or 52 % inhibition, respectively, of 3H-norepinephrine overflow in response to electrical field stimulation and inhibited isoproterenol-stimulated cAMP accumulation by 40 % and 23 % in rabbit iris–ciliary body and cultured nonpigmented epithelial ciliary body cells, respectively.

Aqueous garlic extract when administered intravenously to normotensive dogs produced a significant fall in their mean blood pressure (Malik and Siddiqui 1981). This effect was not antagonised by atropine or antihistamines but was blocked by diamentane. Gastric administration of encapsulated garlic powder to anaesthetised dogs induced dose-dependent (2.5–15 mg/ kg) natriuretic and diuretic responses which reached a maximum 30–40 minutes after garlic administration and decreased to basal levels after 100–150 minutes (Pantoja et al. 1991). A simultaneous decrease in arterial blood pressure was observed which continued past the 250 minutes mark. High garlic doses (15 and 20 mg/kg) provoked bradycardia and T wave inversion during the first 10–15 minutes with recordings returning to normal and staying normal throughout the remainder of the experiment. In-vivo studies demonstrated that garlic blocked hypoxic pulmonary hypertension in rats, exhibiting a combination of endothelium-dependent and endothelium-independent mechanisms for the effect in pulmonary arterial rings (Fallon et al. 1998). The administration of NG-nitro-L-arginine methyl ester (a nitric oxide synthase inhibitor) inhibited the vasodilatory effect of garlic by 80 %.

In another in-vivo study of Sprague–Dawley rats in which high-fructose feeding elicited hyperinsulinaemia, hypertension and hypertriglyceridaemia, administration of allicin for 5 weeks lowered blood pressure, triglyceride and insulin levels (Elkayam et al. 2001). The similar effect of allicin and the antihypertensive drug enalapril on BP, insulin and triglycerides reinforced the trend towards combining the nonpharmacological approach with drug therapy.

Garlic treatment reduced the induction of Na/H exchanger (NHE)-1 only in the unclipped 2K-1C hypertensive rat kidneys, whereas garlic treatment increased the sodium pump activity in both clipped and unclipped 2K-1C kidneys (Al-Qattan et al. 2003). 2K-1C hypertensive animals showed high blood pressure, increased serum concentration of prostaglandin PGE_2 and thromboxane TxB_2 and hypertrophy of the unclipped kidneys, but not in the clipped kidneys. Sodium pump activity was decreased in the clipped kidneys, but remained unchanged in the unclipped kidneys. The findings demonstrated that the antihypertensive action of garlic was associated with a reversal of NHE-1 induction in the unclipped kidneys. These findings indicated the potential use of garlic in the treatment of hypertension. Garlic reduced blood pressure in two-kidney, one-clip (2K-1C) rats and enhanced nitric oxide (NO) synthesis in in-vivo and in-vitro experiments (Al-Qattan et al. 2006). Garlic counteracted the hypertensive effect of L-NITROARGININE-METHYL ester (L-NAME) in normal, unclipped as well as 2K-1C rats. It was concluded that the blood pressure-lowering effect of garlic in the rat 2K-1C model may be partly mediated through the NO pathway. Nwokocha et al. (2011) reported that aqueous garlic extract caused a decrease in blood pressure and bradycardia by direct mechanism not involving the cholinergic pathway in both normotensive and 2K-1C rats, suggesting a likely involvement of the peripheral mechanism for hypotension. Studies showed that aged garlic extract improved blood pressure in spontaneously hypertensive rats more safely than raw garlic (Harauma and Moriguchi 2006). Harmful effects were observed in rats fed with raw garlic, including a decrease in erythrocytes, increase in reticulocytes and generation of papilloma in the forestomach.

Studies found that administration of hydrochlorothiazide (HCTZ) in garlic homogenate pretreated rats with isoproterenol-induced myocardial injury and decreased the QRS duration, RR interval, QT segment, systolic blood pressure, heart rate, serum potassium level, serum lactate dehydrogenase and serum CK-MB (creatine phosphokinase MB) activities and kaliuresis significantly; in contrast, the diuretic effect of HCTZ was significantly increased in presence of garlic (Asdaq and Inamdar 2009). Pharmacokinetic studies showed that garlic increased the bioavailability and half-life, along with a decrease in clearance and elimination rate of HCTZ when administered orally. This could be important in reducing the dose of HCTZ to achieve enhanced therapeutic effect with minimal adverse effect. Studies showed that addition of hydrochlorothiazide (HCTZ) and captopril (CAP) to rats fed with low to moderate doses of garlic elicited synergistic

effects in the biochemical, antioxidant profile and myocardium integrity (Asdaq and Inamdar 2010a). Adding HCTZ/CAP ameliorated the toxic effects of high-dose 500 mg/kg of garlic homogenate. Garlic homogenate at 125 and 250 mg/kg was found to be protective by decreasing the MDA, GSHPx, LDH and CK-MB levels in serum and elevating SOD, CAT, LDH and CK-MB activities in heart tissue homogenate. Addition of HCTZ or CAP was found to augment the garlic homogenate efficacy by keeping the integrity of the myocardium intact. The antioxidant behaviour could be attributed to sulfur-containing compounds such as S-allylcysteine sulfoxide and S-ally mercaptocysteine sulfoxide in garlic homogenate. They found that incorporation of captopril during garlic homogenate administration provided further antioxidant protection to isoproterenol-myocardium injury in rats (Asdaq and Inamdar 2010b). However, higher dose of GH alone or with captopril failed to prevent the damaging effect of isoproterenol. However, higher dose of garlic homogenate alone or with captopril failed to prevent the damaging effect of isoproterenol. The combined therapy of fresh garlic homogenate (FGH) 250 mg/kg and captopril (CAP) was more effective in reducing systolic blood pressure, cholesterol, triglycerides and glucose in albino rats (Asdaq and Inamdar 2010c). The SOD and catalase activities in heart tissue were significantly elevated in rats treated with FGH, *S*-allylcysteine sulfoxide (SACS), CAP, FGH+CAP and SACS+CAP. Further, combined therapy of FGH 250 mg/kg and CAP caused significant fall in LDH and CK-MB activities in serum and elevation in heart tissue homogenate. SACS in low dose was less effective than low dose of FGH; similarly, high dose of FGH was more efficacious than high dose of SACS. Corroborating with this, combined therapy of garlic (250 mg/kg) with CAP demonstrated higher synergistic action than combination of SACS (0.222 mg/kg). Moreover, combination of SACS and CAP exerted super-additive (synergistic) interaction with respect to fall in blood pressure and angiotensin-converting enzyme inhibition. They also found that garlic in moderate dose (250 mg/kg) with added HCTZ possessed synergistic cardioprotective and antihypertensive properties against fructose- and isoproterenol-induced toxicities in albino rats (Asdaq and Inamdar 2011b). They also reported that the bioavailability and half-life of propranolol were significantly enhanced by two- and threefold, respectively, in animals pretreated with 250 mg/kg garlic homogenate (Asdaq and Inamdar 2011a). The combined therapy of garlic 250 mg/kg and propranolol was found to be the most effective in reducing systolic blood pressure, cholesterol, triglycerides and glucose.

Fructose-fed rats showed an increase of systolic blood pressure, aortic NAD(P)H oxidase activity, plasma thiobarbituric acid reactive substances and vascular remodelling that was significantly reduced after aqueous garlic administrations (Vazquez-Prieto et al. 2010). Aqueous garlic extracts prevented oxidative stress and vascular remodelling in rats with metabolic syndrome. In an in-vivo study of Cohen–Rosenthal diabetic hypertensive rats, administration of S-allyl-mercapto-captopril (CPSSA), a conjugate of captopril with allicin, for 2 months was effective in attenuating the systolic and diastolic BP as well as significantly reducing glucose levels and preserving weight gain (Younis et al. 2010). The authors concluded that the combined molecule CPSSA integrated the antihypertensive feature of both allicin and captopril, making it a potential antidiabetic and cardiovascular protective agent.

Intravenous administration of garlic, onion and ginkgo extracts produced dose-dependent and reversible hypotensive and bradycardic effects in anaesthetised normotensive rats (Brankovic et al. 2011). The most effective in reducing arterial blood pressure and heart rate was garlic extract. Processed garlic was found to effectively reduce the blood pressure of spontaneously hypertensive rats after 4, 6 and 8 weeks with a single daily dose of 30 and 50 mg/kg (Han et al. 2011). Animal studies found that the serum antioxidant levels of rats after 3 weeks of garlic treatment were significantly higher than the pretreatment levels in both diabetic and hypertensive rats (Drobiova et al. 2011). The increased serum antioxidant levels were paralleled by a decrease in serum glucose in the garlic-treated diabetic

rats and lowered systolic blood pressure in the garlic-treated hypertensive rats. Studies by Hara et al. (2013) found that aged garlic extract (AGE) significantly reduced left ventricular interstitial fibrosis in Dahl salt-sensitive (DS) rats of 12 and 18 weeks of age. Chronic AGE intake attenuated left ventricular diastolic dysfunction and fibrosis without significantly decreasing systolic blood pressure in hypertensive DS rats.

Clinical Studies

In a randomised, placebo-controlled, double-blind trial of 47 non-hospitalised patients with mild hypertension, garlic intake for 12 weeks resulted in significant differences between the placebo and the garlic group that were found during the course of therapy (Auer et al. 1990). Supine diastolic blood pressure in the group having garlic treatment fell from 102 to 91 mmHg after 8 weeks and to 89 mmHg after 12 weeks. The serum cholesterol and triglycerides were also significantly reduced after 8 and 12 weeks of garlic treatment. A 61-year-old male patient taking garlic 500 mg three times a day for 3 weeks registered a decrease in mean systolic blood pressure by 2 mmHg and a decrease in diastolic blood pressure by 2.4 mmHg (Estrada and Young 1993). The treatment effect of garlic was small, but the patient believed that continuing garlic for the management of his hypertension was justified. In a study of patients with essential hypertension, a moderate decline in blood pressure and a significant reduction in 8-hydroxy-2′-deoxyguanosine, NO levels and lipid peroxidation were observed in patients with garlic pearl supplementation (Dhawan and Jain 2005). Further, a significant increase in vitamin levels and total antioxidant status was also observed in this garlic group as compared to the control subjects. The findings highlighted the beneficial effects of garlic supplementation in reducing blood pressure and counteracting oxidative stress, and thereby, offering cardioprotection in essential hypertensives. In a 4-month study of 23 volunteer subjects with high blood cholesterol (>5.98 mmol/L) comprising 13 hypertensive and ten normotensive patients, garlic extract supplementation improved blood lipid profile, strengthened blood antioxidant potential and produced significant reductions in systolic and diastolic blood pressures (Durak et al. 2004). It also led to a decrease in the level of oxidation product (malondialdehyde) in the blood samples, which demonstrated reduced oxidation reactions in the body. Sobenin et al. (2009) conducted a double-blind, placebo-controlled trial with an active control arm, and the hypotensive action of time-released garlic powder tablets (Allicor) was compared with that of regular garlic pills (Kwai) in 84 men with mild or moderate arterial hypertension. The results revealed that time-released garlic powder tablets were more effective for the treatment of mild and moderate arterial hypertension than regular garlic supplements. In a double-blind, parallel, randomised, placebo-controlled trial involving 50 patients, administration of garlic extract (960 mg containing 2.4 mg *S*-allylcysteine) daily for 12 weeks was found to be superior to placebo in lowering systolic blood pressure similarly to current first-line medications in patients with treated but uncontrolled hypertension (Ried et al. 2010). In a placebo-controlled trial of 44 hypertensive subjects over a period of 8 weeks, ingestion of 500 mg capsules of processed garlic significantly lowered the blood pressure (SBP) after only 2 weeks, while a significant reduction in diastolic blood pressure (DBP) took 8 weeks (Han et al. 2011).

In a prospective and uncontrolled clinical study of 70 subjects aged 30–60 years with primary arterial hypertension, including 38 females and 32 males, garlic administration was found to significantly lower lipid level and the level of lipid peroxidation products in the blood (Duda et al. 2008). It markedly increased vitamin E concentration in the serum, whereas the increases in the levels of other antioxidant vitamins and glutathione peroxidase activity proved insignificant. The product did not affect arterial blood pressure in the study subjects.

Reviews/Meta-analysis Studies

Results of a systematic review and meta-analysis conducted by Silagy and Neil (1994a) suggested that garlic powder preparation may be of some clinical use in subjects with mild hypertension. However, there was still insufficient evidence to

recommend it as a routine clinical therapy for the treatment of hypertensive subjects. The meta-analysis of 11 of 25 review studies conducted by Ried et al. (2008) suggested that garlic preparations were superior to placebo in reducing blood pressure in individuals with hypertension. Stabler et al. (2012) conducted a systematic review of randomised, placebo-controlled trials of any garlic preparation versus placebo for the treatment of hypertension. From 2 trials in 87 hypertensive patients, it was suggested that garlic reduced mean supine systolic and diastolic blood pressure by approximately 10–12 mmHg and 6–9 mmHg, respectively, over and above the effect of placebo, but the confidence intervals for these effect estimates were not precise, and this difference in blood pressure reduction fell within the known variability in blood pressure measurements. There was insufficient evidence to determine if garlic provided a therapeutic advantage versus placebo in terms of reducing the risk of mortality and cardiovascular morbidity in patients diagnosed with hypertension.

Cardioprotective Activity

Cardioprotective effects of dietary garlic had been reported to be mediated in large part via the generation of hydrogen sulfide (H_2S) (Ginter and Simko 2010; Lavu et al. 2011). Garlic-derived organic polysulfides were reported to be converted by erythrocytes into hydrogen sulfide which relaxed the vascular smooth muscle, inducing vasodilation of blood vessels and significantly reducing blood pressure. Despite the controversial role of H_2S in blood pressure regulation and interaction with nitric oxide, H_2S, through its antiapoptotic, anti-inflammatory and antioxidant effects, had demonstrated significant cardioprotection (Lavu et al. 2011). Extensive studies had been reported indicating that garlic and its constituents reduced cardiovascular risk, including abnormal plasma lipids, oxidised low-density lipoproteins (LDL), abnormal platelet aggregation and high blood pressure (Ginter and Simko 2010). Stimulation of nitric oxide generation in endothelial cells appeared to be the critical preventive mechanism, and garlic may promote an anti-inflammatory environment by cytokine modulation in human blood. Also data on the potential ability of garlic to inhibit the rate of progression of coronary calcification had been reported. Epidemiological studies show an inverse correlation between garlic consumption and progression of cardiovascular disease (Rahman and Lowe 2006). Numerous in-vitro studies have confirmed the ability of garlic to reduce serum total cholesterol, LDL and LDL oxidation, platelet aggregation, hypertension and smoking and to increase antioxidant status.

In-Vitro Studies

Allicin, from garlic, markedly inhibited nitrite production in lipopolysaccharide (LPS)-stimulated rat cardiac myocytes (Schwartz et al. 2002). A low concentration of allicin (10 μM) was significantly more potent in abrogating the effect of LPS on nitrite production than a higher concentration (40 μM). Allicin decreased steady-state iNOS mRNA levels, and this effect was maximal when a lower concentration was used (10 μM compared with 40 μM). Allicin inhibited the uptake of 1 mM extracellular arginine in a concentration-dependent manner in rat cardiac myocytes. A concentration of 200 μM allicin abolished the expression of CAT-2 mRNA, 100 μM significantly attenuated it, whereas 50 μM had no effect. The results suggested that allicin inhibited iNOS activity through two different mechanisms: at lower concentrations it decreased iNOS mRNA levels, whereas at higher concentrations it inhibited arginine transport through downregulation of cationic amino acid transporter-2 (CAT-2) mRNA. Benavides et al. (2007) showed that human RBCs converted garlic-derived organic polysulfides into hydrogen sulfide H_2S, an endogenous cardioprotective vascular cell signalling molecule. Intact aorta rings, under physiologically relevant oxygen levels, also metabolised garlic-derived organic polysulfides to liberate H_2S. The vasoactivity of garlic compounds was synchronous with H_2S production, and their potency to mediate relaxation increased with H_2S yield, strongly supporting the hypothesis that H_2S mediated the vasoactivity of garlic.

Allitridin (diallyl trisulfide, DATS) from garlic inhibited multiple cardiac potassium channels strongly of hKv4.3 and weakly of hKv1.5, hERG and hKCNQ1/hKCNE1 channels expressed in HEK 293 cells (Xu et al. 2012). These effects may account for its anti-arrhythmic effect observed in experimental animal models. Allitridin (diallyl trisulfide) of garlic and amiodarone exhibited similar effects on the cardiac conduction system and on the electrophysiology without RUD (reverse use dependence) in the isolated hearts of normal rats and rats with myocardial infarction (Xing et al. 2012). These effects may be the result of the use of multi-channel blockers, such as calcium channel blockers and IKr and IKs channel blockers. The data indicated that allitridin may be a promising anti-arrhythmic drug.

Animal Studies

Studies showed that chronic garlic intake (125–500 mg/kg) in rats dose dependently augmented endogenous antioxidants SOD (superoxide dismutase), catalase, GPx (glutathione peroxidase) and GSH (reduced glutathione) and lowered myocardial TBARS (thiobarbituric acid reactive substances), and all these may have important direct cytoprotective effects on the heart, especially in the event of oxidant stress-induced injury (Banerjee et al. 2002). Chronic oral administration of raw garlic provided protection against isoproterenol-induced myocardial necrosis and associated oxidative stress in Wistar albino rats (Banerjee et al. 2003). Significant preservation of myocardial SOD activity and significant reduction in plasma TBARS and LDH levels were observed in garlic-treated rats. Isoproterenol-induced myocardial morphological changes were least in the 250 and 500 mg/kg garlic-treated groups. Administration of garlic oil produced a marked reversal of the adverse metabolic changes related to myocardial infarction induced by isoproterenol in rats (Saravanan and Prakash 2004). These adverse metabolic changes induced by isoproterenol included significant increase in lipid peroxide levels and serum iron content with a significant decrease in plasma iron binding capacity, ceruloplasmin activity and glutathione (GSH) level and a significant decrease in antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPX), glutathione S-transferase (GST) and glutathione reductase (GRD) in the heart. Medicinal garlic was found to have potential to ameliorate the myocardial damage induced by isoprenaline in rats (Vibha et al. 2011). It caused significant elevation in superoxide dismutase and catalase activities and reduction in thiobarbituric acid reactive species levels compared to isoprenaline control. Lactate dehydrogenase (LDH) and creatine phosphokinase-MB (CK-MB) activities were decreased in serum and elevated in the heart tissue of animals treated with low and high doses of medicinal garlic. Studies showed that adenosine was involved in the cardioprotective and cardiodepressant activities of aqueous garlic extract in ischaemic preconditioning and myocardial ischaemia–reperfusion-induced cardiac injury and was mediated by the modulation of nitric oxide in rats (Sharma et al. 2012). The cardioprotective effect of ischaemic preconditioning and garlic cardioprotection was significantly attenuated by theophylline (1,000 μmol/L) and 8SPT (10 mg/kg, i.p.) and expressed by increased myocardial infarct size, increased LDH level and reduced nitrite and adenosine levels.

Aged garlic extract showed dose-dependent cardioprotection in isoproterenol-induced cardiac toxicity in rats (Avula et al. 2014). Aged garlic extract (AGE) and its constituent, S-allylcysteine (SAC), administration caused a decrease in serum lactate dehydrogenase (LDH) and creatinine kinase-MB (CK-MB) activities and an elevation of LDH and CK-MB activities in heart tissue homogenate. The isoproterenol-induced ECG changes were restored to normal in all treated groups. However, concurrent administration of SAC with atenolol (6 mg/kg, p.o) combated more effectively the myocardial dysfunction during isoproterenol-induced cardiotoxicity in rats. Garlic extract at both concentrations significantly decreased the plasma insulin, total cholesterol, homeostasis model assessment index and oxidative stress levels in obese insulin-resistant rats caused by a high-fat diet for 12 weeks (Supakul et al. 2014). Furthermore,

garlic extract at both doses (250 or 500 mg/kg/ day) restored the heart rate variability, cardiac function and cardiac mitochondrial function. The study by Padiya et al. (2014) demonstrated that the raw garlic homogenate was effective in reducing cardiac hypertrophy and fructose-induced myocardial oxidative stress through PI3K/AKT/Nrf2-Keap1 dependent pathway in fructose-fed diabetic rats.

Clinical/Epidemiological Studies

In a pilot questionnaire study of 101 adult subjects, in Karachi, Pakistan, Qidwai et al. (2000) found that 67 % of the subjects used garlic in cooked food, while the rest used either in the raw form or in pickles. 59 % thought that dietary use of garlic was healthy. Subjects with blood pressure on the lower side were found to consume more garlic in their diets.

Administration of garlic oil (four capsules twice daily for 6 weeks) to 30 patients of coronary artery disease significantly reduced heart rate at peak treadmill exercise and also significantly reduced the workload upon the heart resulting in better exercise tolerance as compared to the initial test (Verma et al. 2005). Garlic appeared to be a good adaptogen to be utilised in patients with coronary artery disease.

In a double-blind, crossover, randomised, placebo-controlled clinical trial on subjects with metabolic syndrome, administration of aged garlic extract (AGE) for 12 weeks increased plasma adiponectin levels (Gómez-Arbeláez et al. 2013). The data that AGE might be a useful, novel, non-pharmacological therapeutic intervention to increase adiponectin and to prevent cardiovascular (CV) complications in individuals with metabolic syndrome.

Antihyperglycaemic/Antidiabetic Activity

In-vivo studies suggested that garlic reduced lipid synthesis and influenced glycogen metabolism in the liver of rats (Chang and Johnson 1980). Nyyer et al. (1989) found that the petroleum ether garlic extract and crude garlic juice had some hypoglycaemic effect on the induced hyperglycaemia in experimental rabbits, whereas no effect was observed on the group fed on ethanol garlic extract. The hypoglycaemic effect of garlic appeared to be associated with the increase of insulin level. Administration of S-allylcysteine sulfoxide (SACS), a garlic sulfur-containing amino acid, at a dose of 200 mg/kg body weight decreased significantly the concentration of serum lipids, blood glucose and activities of serum enzymes like alkaline phosphatase, acid phosphatase and lactate dehydrogenase and liver glucose-6-phosphatase in alloxan-induced diabetic rat (Sheela and Augusti 1992; Augusti and Sheela 1996). It increased significantly liver and intestinal HMG-CoA reductase activity and liver hexokinase activity. SACS ameliorated the diabetic condition almost to the same extent as did glibenclamide and insulin. In addition, SACS controlled lipid peroxidation better than the other two drugs. Furthermore, SACS significantly stimulated in-vitro insulin secretion from B cells isolated from normal rats. Hence it was suggested that the beneficial effects of SACS could be due to both its antioxidant and its secretagogue actions. Oral administration of onion and garlic sulfoxide amino acids, viz. S-methylcysteine sulfoxide (SMCS) and S-allylcysteine sulfoxide (SACS) to alloxan-induced diabetic rats for a month, ameliorated their diabetic condition, being characterised by glucose intolerance, weight loss, depletion of liver glycogen, etc., and was ameliorated as comparable to rats treated with glibenclamide and insulin (Sheela et al. 1995).

Intraperitoneal administration of aqueous garlic extract for 8 weeks significantly improved the impaired endothelium-dependent relaxations and decreased the enhanced contractile response to phenylephrine in streptozotocin-induced diabetic rats (Baluchnejadmojarad et al. 2003). It was concluded that intraperitoneal administration of aqueous garlic extract could improve endothelial dysfunction in the insulin-dependent model of uncontrolled diabetes. Also they demonstrated that garlic extract treatment partially attenuated the increased contractile responses of aortic rings exposed to acetylcholine in

8-week streptozotocin-induced diabetic rats (Baluchnejadmojarad and Roghani 2003).

Oral administration of garlic or onion juice daily for 4 weeks to alloxan-induced diabetic rats reverted the adverse biochemical changes induced by alloxan such as significant elevation of plasma levels of glucose, urea, creatinine and bilirubin; significant increase of aspartate aminotransferase (AST), alanine aminotransferase (ALT), lactate dehydrogenase (LDH) and alkaline and acid phosphatase (AlP, AcP) activities in plasma and testes and their reduction in the liver; significant increase in brain LDH; and increase in the concentration of thiobarbituric acid reactive substances and activity of glutathione S-transferase in the plasma, liver, testes, brain, and kidney (El-Demerdash et al. 2005). Compared to the consumption of fenugreek and onion, only the consumption of garlic by alloxan-induced diabetic rats was able to reduce blood glucose significantly compared with the control group (Jelodar et al. 2005). In the control positive group, all the mentioned morphometric factors, volume density of B cells, volume density of islets, percent of B cells, number of islets per square millimeter, average area of islets and average volume density of B cell in the whole pancreas, were significantly changed in comparison with the control negative (normal health) group, but the same did not show significant change between treated and untreated diabetics. Oral administrations of garlic extract significantly decreased serum glucose, total cholesterol, triglycerides, urea, uric acid, creatinine and AST and ALT levels, but increased serum insulin in streptozotocin-induced diabetic rats, but not in normal rats (Eidi et al. 2006). The antidiabetic effect of the extract was more effective than that observed with glibenclamide.

Both garlic oil and diallyl trisulfide improved glycaemic control in streptozotocin-induced diabetic rats through increased insulin secretion and increased insulin sensitivity (Liu et al. 2005). They also found that long term (16 weeks) of streptozotocin-induced diabetic rats with garlic oil could improve oral glucose tolerance and renal function (proteinuria) but not through the action of diallyl disulfide (DADS) (Liu et al. 2006). High doses of DADS may further complicate the metabolic disturbances in diabetes.

Zn(II) complex ($Zn(alx)_2$) with allixin (Halx) isolated from garlic exhibited the relatively high in-vitro insulin-mimetic activity, as determined by the inhibition of free fatty acid (FFA) release in isolated rat adipocytes treated with epinephrine (Adachi et al. 2006b). In type 2 diabetic KKA^y mice, $Zn(alx)_2$ exhibited higher antidiabetic activity than $Zn(ma)_2$ by daily intraperitoneal injections for 2 weeks. In addition, daily oral administrations of $Zn(alx)_2$ lowered the high blood glucose levels in KKA^y mice; however, the effect was not so high. Three $Zn(alx)_2$-related complexes were newly prepared, and a Zn(II) complex ($Zn(tanm)_2$) with 1,6-dimethyl-3-hydroxy-5-methoxy-2-pentyl-1,4-dihydropyridine-4-thionato was found to have extremely high in-vitro insulin-mimetic activity. They also found that $Zn(alx)_2$ and $Zn(ma)_2$ normalised hyperglycaemia in KK-A(y) mice after a 14-day course of daily intraperitoneal injections (Adachi et al. 2004). However, Zn(alx)(2) improved glucose tolerance in KK-A(y) mice much more than did Zn(ma)(2), indicating that Zn(alx)(2) possessed greater in-vivo antidiabetic activity than Zn(ma)(2). In addition, Zn(alx)(2) improved leptin resistance and suppressed the progress of obesity in type 2 diabetic KK-A(y) mice. On the basis of these observations, it was concluded that the Zn(alx)(2) complex may be a novel potent candidate for the treatment of type 2 diabetes mellitus. Following in-vitro and in-vivo studies on a group of bis(3-hydroxy-4-pyronato)oxovanadium(IV) complexes with VO coordination mode, bis(allixinato)oxovanadium(IV) containing allixin, a garlic component, was found to be the most potent antidiabetic agent among them (Adachi et al. 2006a). This allixin-containing complex with a high in-vitro insulin-mimetic activity in terms of both free fatty acid (FFA) release inhibitory and glucose uptake-enhancing activities in isolated rat adipocytes exhibited a high hypoglycaemic effect in type 1 diabetic model mice by both intraperitoneal injections and oral administrations. Bis(allixinato)

oxovanadium(IV) was thus proposed to be one of the most effective candidates for antidiabetic therapy. In an animal model of type 2 diabetes, feeding of db/db mice for 7 weeks with aged black garlic exerted stronger antioxidant activity than normal garlic indicating the usefulness of black garlic in diabetic complications (Lee et al. 2009b). Consumption of aged black garlic significantly decreased hepatic thiobarbituric acid reactive substances (TBARS) level compared with the garlic group which showed lower TBARS level than the control group. Activities of superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) of garlic and aged black garlic group were significantly elevated compared to the control group. Catalase (CAT) activity of aged black garlic group was increased compared with the control group. The antioxidant activity of garlic and aged black garlic as measured in scavenging free radicals by the Trolox equivalent antioxidant capacity (TEAC) assay was 13.3 and 59.2 μmol/g wet weight, respectively. In-vivo studies showed that fasting serum glucose and blood glycated haemoglobin levels were significantly decreased, and insulin level was significantly increased in db/db mice fed with garlic compared with the control group (Seo et al. 2009). Consumption of aged black garlic significantly decreased the homeostasis model assessment for insulin resistance (HOMA-IR) and tended to decrease serum glucose. Garlic consumption significantly decreased total cholesterol, while aged black garlic significantly reduced serum total cholesterol and triglyceride and increased HDL cholesterol levels. These results suggested that garlic exerted hypoglycaemic and hypocholesterolaemic effect, and aged black garlic improved insulin sensitivity and dyslipidaemia in db/db mice.

Compared to non-treated diabetic rats, garlic- or ginger-treated diabetic rats' serum glucose and protein clearance levels decreased by 45 % and 50 %, respectively (Al-Qattan et al. 2008). Images of non-treated diabetic kidneys showed characteristic histopathological changes (e.g. capsular space shrinkage, glomerular hypertrophy and diffusion, glomerular and microvascular eosinophilic precipitation and cytoplasm fragmentation and retraction). In garlic- or ginger-treated rats, these renal nephropathic structural changes although evident were less prominent. Garlic and ginger ameliorated the biomarkers of diabetes and diabetic nephropathy in streptozotocin-induced diabetic rats (Thomson et al. 2013). Garlic treatment of diabetic animals resulted in a modest weight gain and decreased food (but not water) intake and urine output. Blood glucose and serum creatinine, fructosamine and uric acid were significantly elevated in diabetic rats and were significantly lowered by ginger and garlic. In contrast, serum protein, albumin and insulin levels decreased significantly in diabetic rats, while the ginger- and garlic-treated diabetic rats had increased serum levels of protein, albumin and insulin. Garlic and ginger treatment significantly decreased the elevated total urine protein, albumin and albumin/creatinine ratio and glycated haemoglobin levels in diabetic animals.

Aqueous garlic extract was found to attenuate glomerular glycation in streptozotocin-induced diabetic rats (Al-Qattan et al. 2013). This effect could be partially mediated via euglycaemia induced by revitalisation of endogenous insulin. Serum glucose, triglycerides, total lipids, total cholesterol, low-density lipoprotein (LDL) and very-low-density lipoprotein (VLDL) cholesterol in alloxan-induced diabetic rats treated with alliin produced from leaves of in situ-grown garlic plants elicited significant reduction of ~54 %, 15 %, 14 %, 20 %, 24 % and 15 %, while 35 %, 14 %, 10 %, 12 %, 17 % and 11 % reduction was noted in diabetic rats treated with alliin produced from ex situ-grown plants in comparison with those administered with distilled water (Nasim et al. 2011). High-density lipoprotein (HDL) cholesterol did not show any significant change. Leaf extract of plants lowered serum enzyme levels (alkaline phosphatase, aspartate aminotransferase and alanine aminotransferase) towards the norm better than glibenclamide. The histopathological alteration in the pancreas caused by alloxan was also reduced by the leaf extract. Treatment with garlic extract significantly

reduced the elevated blood glucose level and augmented the decreased catalase activity in streptozotocin-induced diabetic rats (Mahmoud and Abdalla 2011). Garlic extract also significantly increased reduced glutathione content and decreased caspase-3 protein in the pancreatic tissue. The results revealed that the aqueous extract of raw garlic may have antioxidant and antiapoptotic activity in the treatment of diabetes mellitus.

Administration of garlic juice 3 weeks before streptozotocin injection prevented and ameliorated the deleterious biochemical and histopathological effects in the pancreas and liver in streptozotocin (STZ)-induced diabetic rats (Masjedi et al. 2013). Administration of S-allylcysteine, a garlic derivative to streptozotocin (STZ)-induced diabetic rats, led to a decrease in the levels of glucose, CYP2E1 activity, TBARS and ceruloplasmin (Saravanan and Ponmurugan 2013). Additionally, the levels of plasma insulin and enzymatic and nonenzymatic antioxidants leptin and adiponectin were increased in SAC-treated diabetic rats.

The garlic extract was found to be effective in improving the high fructose-induced oxidative stress, inflammation and insulin resistance in male Wistar rats (Sivaraman et al. 2013). *Allium sativum* and *Allium porrum* inhibited significantly the active transport of D-glucose across rat enterocytes in the rat everted intestinal sac experiment (Belemkar et al. 2013). Increased concentrations of both at 2.2 and 5.0 mg/mL in the mucosal solution significantly decreased the absorption as well as transport across the rat intestine. D-glucose absorption along with transport was significantly inhibited at 2.5 and 5 mg/mL of garlic and leek compared to the control experiment groups. *A. porrum* showed more potent action.

Immunomodulatory/ Haemagglutination Activity

A mannose-binding lectin ASA was isolated from garlic (Kaku et al. 1992). ASA reacted strongly with a synthetic linear (1→3)-α-d-mannan and *Saccharomyces cerevisiae* mannan, weakly with a synthetic (1→6)-α-D-mannan, and failed to precipitate with galactomannans from *Torulopsis gropengiesseri* and *T. lactis-condensi*, a linear mannopentaose, and murine IgM. The *N*-terminal amino acid sequence of ASA exhibited 79 % homology with that of ransom (*Allium ursinum*) lectin AUA and moderately high homology (53 %) with that of snowdrop bulb lectin, also an α-D-mannosyl-binding lectin. Fraction 4 (F4), a protein fraction isolated from aged garlic extract, enhanced the cytotoxicity of human peripheral blood lymphocytes (PBL) against both natural killer (NK)-sensitive K562 and NK-resistant M14 cell lines (Morioka et al. 1993). Administration of F4 (5 μg/mL) with 10 U/mL interleukin IL-2 generated lymphokine-activated killer activity equivalent to that produced by 100 U/mL IL-2 alone against M14. F4 also enhanced concanavalin A-induced IL-2 receptor (Tac) expression and IL-2 production of human peripheral blood lymphocytes. The results indicated F4 to be a very efficient immunopotentiator and may be used for immunotherapy.

Alliin exerted an immunomodulatory effect on certain functions of the peripheral blood mononuclear cells in-vitro (Salman et al. 1992). When macrophages were treated with various doses (1, 10, 100 ng/mL) of allicin from garlic, for 20 hours, allicin induced tumouricidal activity and increased the production of tumour necrosis factor (TNF-α) and nitric oxide (NO) in a dose-dependent manner (Kang et al. 2001). However, there was a little alteration on phagocytosis and the production of hydrogen peroxide (H_2O_2), interleukin 1 (IL-1) and IL-6. The results indicated that NO and TNF-α were likely major mediators of tumouricidal activity in allicin-treated macrophages and suggested allicin to be an efficient immunomodulator of macrophage secretory and cellular activities, showing a differential effect on the production of cytokines and cytotoxic molecules. Garlic aqueous and ethanolic extracts significantly modulated lymphocyte proliferation, triggered by the potent T-cell mitogen concanavalin A (Con A) (Čolić et al. 2002). Generally, higher

concentrations of the extracts showed inhibitory effects, whereas lower concentrations significantly augmented the proliferation of lymphocytes. The stimulatory effect of aqueous extract was stronger using splenocytes and suboptimal concentrations of Con A as a consequence of increased interleukin 2 (IL-2) production as well as the expression of IL-2 receptor α (IL-2Rα). The inhibitory effect of aqueous extract correlated with a decrease in IL-2 production, but was not followed by the downregulation of IL-2Rα expression. Studies demonstrated that immune-mediated, concanavalin A (Con A)-induced liver damage in mice could be prevented by allicin, probably because of its immunomodulatory effects on T cells and adhesion molecules and inhibition of NF-κB activation (Bruck et al. 2005). In-vitro studies showed that allicin inhibited the apoptosis of macrophages in a depleted nutritional state through the mitogen-activated protein kinase/extracellular signal-regulated kinase–kinase pathway and increasing the level of ERK1/2 phosphorylation (Cho et al. 2006).

Two major proteins (12–14 kDa) were detected in aged garlic extract; the purified protein components QA-1, QA-2 and QA-3 displayed immunomodulatory and mannose-binding activity (Chandrashekar and Venkatesh 2009). QA-2 showed the highest mitogenic activity. The identity of QA-2 and QA-1 proteins with the garlic lectins ASA I and ASA II, respectively, had been confirmed by haemagglutination analysis. QA-3 exhibited mitogenic activity, but no haemagglutination activity. Aged garlic had been reported to have more potent immunomodulatory effects than raw garlic, and these effects had been attributed to the transformed organosulfur compounds. The study here showed that immunomodulatory proteins could also contribute to the immunomodulatory activity of aged garlic extract. A 14 kDa protein molecule isolated from garlic suppressed indoleamine 2, 3-dioxygenase metabolites in mononuclear cells and increased the proliferation responses of mononuclear in-vitro (Nikoo et al. 2008).

Three immunomodulatory protein components of molecular weight ~13 kD (QR-1, QR-2 and QR-3 in the ratio 7:28:1) were separated from raw garlic extract (Clement et al. 2010). All the 3 proteins exhibited mitogenic activity towards human peripheral blood lymphocytes, murine splenocytes and thymocytes. The mitogenicity of QR-2 was the highest among the three immunomodulatory proteins. QR-1 and QR-2 displayed haemagglutination and mannose-binding activities; QR-3 showed only mannose-binding activity. Immunoreactivity of rabbit anti-QR-1 and anti-QR-2 polyclonal antisera showed specificity for their respective antigens as well as mutual cross-reactivity; QR-3 was better recognised by anti-QR-2 (82 %) than by anti-QR-1 (55 %). QR-2 induced a 2-fold higher histamine release in-vitro from leucocytes of atopic subjects compared to that of non-atopic subjects. In all functional studies, QR-2 was more potent compared to QR-1. The results indicated that the two major proteins QR-2 and QR-1 present in a ratio of 4:1 in raw garlic contribute to garlic's immunomodulatory activity, and their characteristics were markedly similar to the abundant *Allium sativum* agglutinins (ASA) I and II, respectively. Garlic lectins ASA I and ASA II were moderately stable in simulated gastric fluid for up to 30 minutes; while they retained haemagglutination activities, immunoreactivity with the respective rabbit antiserum decreased immediately (0.5 minutes) to 10–30 % (Clement and Venkatesh 2010). ASA I retained ~80 % haemagglutination activity in the pH range 2–12; however, ASA II retained only 40 % in the pH ranges 2–4 and 10–12. Garlic lectins exposed to 60 °C (30 minutes) and pepsin (1 and 2 minutes) retained haemagglutination and phagocytic activities. Garlic lectins were found to be immunogenic upon oral feeding in BALB/c mice. A lectin-specific serum IgG response was seen in mice comparable to the oral immunogen, phytohaemagglutinin. The recovered lectin in faeces of mice administered with garlic lectins showed antigenicity identical to that of the administered proteins. The stabilities of the garlic lectins, their ability to withstand the gastrointestinal passage and their recognition by the immune system upon oral feeding reinforced the reported presence of natural antibod-

ies to garlic proteins in normal human sera. Garlic extract (GaE) is protected against methylmercury (MeHg)-induced cytotoxic effects and MeHg-induced inhibition of adenosine deaminase activity on human leucocytes under in-vitro conditions (Abdalla et al. 2010). The protective effects of garlic extract against MeHg-induced leucocyte damage were related to the removal of oxidant species generated in the presence of MeHg due to the antioxidant efficacy of garlic constituents. 14-kDa and 47-kDa protein molecules of aged garlic extract were able to suppress NO production from peritoneal macrophages (Daneshmandi et al. 2011). These molecules had no cytotoxic effect on macrophages and did not increase tumouricidal property of macrophages. 14-kDa and 47-kDa protein molecules of aged garlic extract were able to suppress NO production from peritoneal macrophages (Daneshmandi et al. 2011). These molecules had no cytotoxic effect on macrophages and did not increase tumouricidal property of macrophages.

A dual function protein with proteolytic and haemagglutinating activities was isolated from garlic bulbs (Parisi et al. 2008) It had a molecular mass of 25–26 kDa and comprised of two polypeptide chains of 12.5 kDa. The N-terminus of the protein displayed a 100 % sequence similarity to the sequences of a mannose-binding lectin isolated from garlic bulbs. It exhibited characteristics similar to cysteine peptidase. The enzyme exhibited substrate specificity and hydrolysed natural substrates such as α-casein, azocasein, haemoglobin and gelatin. It also showed a high affinity for synthetic peptides such as Cbz-Ala-Arg-Arg-OMe-β-Nam. The purified protein was able to agglutinate trypsin-treated rabbit red cells. Both high molecular weight (>3.5 kDa; HF) and low molecular weight (<3 kDa; LF) fructans isolated from aged garlic extract exhibited immunomodulatory activity, namely, lymphocyte proliferation and macrophage activation including phagocytosis (Chandrashekar et al. 2011). These activities were comparable to that of known polysaccharide immunomodulators such as zymosan and mannan.

Studies revealed that CD4 and total white blood cell (WBC) counts were significantly increased in a dose-dependent manner in both onion- and garlic-treated rats when compared to the zero control (Mirabeau and Samson 2012). Extract of garlic at 750 mg/Kg/day significantly increased the CD4 cells and total white cell count when compared to other concentrations. However, no significant effect was observed on these parameters when extracts were combined. The results from this study revealed the immune-boosting capabilities of onion and garlic, but underscored their synergistic activities. In contrast to control rats, garlic essential oil-treated gastric rats dose dependently and significantly increased the percent of CD3 and CD4 leucocytes in garlic-treated rats (Li et al. 2010). The detection of a significant increment in the ratio of CD4/CD8 leucocytes in the serum of rats after administration of garlic essential oil indicated that garlic essential oil may be useful for treatment of patients with inflammatory disease, e.g. gastric cancer.

Garlic consumption in mice not only caused increased energy demand from the faster RBC turnover but also increased the production of CO, which in turn stimulated splenic erythropoiesis by an erythropoietin-independent mechanism, thus completing the sequence of feedback regulation for RBC metabolism (Akgül et al. 2010). Dietary garlic supplementation and CO treatment showed additive effects on reducing plasma erythropoietin levels in mice. Studies showed that gavage administration of male Wistar rats with garlic solution may enhance lymphocyte proliferation in the spleen and thymus from the rat immune system (Zamani et al. 2011). In spite of a decline in the average nuclear area and nuclear length of thymocytes from garlic-treated rats, total AgNORs (argyrophilic nucleolar organiser regions) and total AgNORs length increased significantly in the splenocytes and thymocytes of the garlic-treated rats. Treatment of dendritic cells from the spleen of BALB/c mice with 47 kDa protein isolated from aged garlic lowered the expression of dendritic cell maturation markers including: CD40, CD86 and MHC-II which was similar to tolerogenic dendritic cell phenotype (Ahmadabad et al. 2012). The study demonstrated that 47 kDa

protein purified from aged garlic could be considered as a potential candidate to generate tolerogenic dendritic cells in-vitro. The 70 % ethanol black garlic extracts (BGE) at 70 °C for 12 hours showed the strongest antioxidant and anticancer activities (Purev et al. 2012). It was found that the cell proliferation, TNF-α and NO production of primary immune cells obtained from volunteers' blood treated with 70 % raw garlic extract (70 % RGE) were significantly different; however, little difference was observed for the 70 % BGE treatment. BGE showed stronger immunostimulatory activities than RGE.

Administration of aged garlic fructans produced a significant humoral (serum IgG) response to ovalbumin antigen in BALB/c mice though the immunoadjuvant response was delayed (Chandrashekar and Venkatesh 2012). Garlic polysaccharide was modified by HNO_3-Na_2SeO_3 method to obtain nine selenising garlic polysaccharides, sGPS1–sGPS9 (Qiu et al. 2014). The results showed that sGPSs could significantly promote lymphocyte proliferation in-vitro, with sGPS3, sGPS5 and sGPS6 presenting stronger efficacy. In-vivo, 14-day-old chickens injected, respectively, with sGPS3, sGPS5 and sGPS6 could significantly promote lymphocyte proliferation and enhance serum antibody titre, IFN-γ and IL-2 contents. The results indicated that selenylation modification could significantly enhance the immune-enhancing activity of GPS, with sGPS6 possessing the best efficacy and could be as a candidate drug of immunoenhancer.

In a randomised study of 60 healthy volunteers, oral intake of 1 and 3 g doses of garlic traditionally used for daily supplementation increased urinary levels of interleukin IL-12, a potent stimulator of T helper cell 1 (Th-1) immune responses (Alma et al. 2014).

Anti-inflammatory Activity

Garlic oil exhibited anti-inflammatory activity, and it suppressed rat paw edema inflammation induced by formalin and histamine (Nemat et al. 2013). It was as effective as the nonsteroidal anti-inflammatory drug indomethacin. Using a chemotactic gradient Labchip to study cell migration, garlic oil was found to be a potential inhibitor for neutrophil-like cell migration and chemotactic responsiveness (Shih et al. 2010). Garlic oil treatment lowered the values of chemotactic index (CI) and motility index (MI) and reduced the average speed of cell migration from 13 to 8 μm/minute. The authors also suggested that the anti-inflammatory activity exhibited by garlic oil was mainly through inhibiting the assembly–disassembly processes of the cytoskeleton.

Studies by Lee et al. (2011) showed that aged black garlic possessed anti-inflammatory activity and may have a potential therapeutic use for the prevention and treatment of vascular diseases such as atherosclerosis through mechanisms involving the inhibition of VCAM-1 expression and NF-κB activation in vascular endothelial cells. The chloroform extract of aged black garlic significantly inhibited TNF-α-induced reactive oxygen species (ROS) formation and suppressed TNF-α-induced mRNA expression of VCAM-1 in human umbilical vein endothelial cells (HUVECs). In addition, treatment of HUVECs with CEABG markedly reduced THP-1 monocyte adhesion to TNF-α-stimulated HUVECs and significantly inhibited NF-κB transcription factor activation.

Aged red garlic (ARG) treatment markedly reduced LPS-induced nitrite production in RAW 264.7 macrophages and reduced inducible nitric oxide synthase (iNOS) expression (Park et al. 2012a). Treatment of cells with ARG led to a significant increase in haeme oxygenase-1 (HO-1) protein expression, which was mediated by stimulating the expression of nuclear factor erythroid 2-related factor 2 (Nrf2). In LPS-induced inflammatory mice, ARG treatment downregulated iNOS and COX-2 expressions, while it upregulated HO-1 expression.

Ajoene, from garlic, dose dependently inhibited the release of lipopolysaccharide (LPS) (1 μg/mL)-induced prostaglandin E_2 in RAW 264.7 macrophages (IC_{50} value: 2.4 μM) (Dirsch and Vollmar 2001). This effect was found to be

due to an inhibition of COX-2 enzyme activity by ajoene (IC_{50} value: 3.4 μM). The effect of ajoene was found to be similar to that of indomethacin. Allicin (20–100 μm) inhibited the SDF-1alpha (CXCL12)-induced T-cell migration through fibronectin by the downregulation of (1) the reorganisation of cortical actin and the subsequent T-cell polarisation and (2) T-cell adhesion to fibronectin (Sela et al. 2004). Allicin also inhibited T-cell adhesion to endothelial cells and transendothelial migration. These inhibitory effects of allicin were associated with its ability to downregulate the phosphorylation of Pyk2 and to reduce the expression of the VCAM-1- and FN-specific α4β1 integrin (VLA-4). The data suggested the beneficial biological effects of allicin in processes where T cells play an important role and suggested that allicin may be used therapeutically with chronic inflammatory diseases. Studies suggested that allicin exerted an inhibitory immunomodulatory effect on intestinal epithelial cells and suggested that allicin may have the potential to attenuate intestinal inflammation (Lang et al. 2004). Allicin markedly inhibited the spontaneous and TNF-α-induced secretion of interleukin IL-1β, IL-8, IP-10 and MIG from HT-29 and Caco-2 cell lines in a dose-dependent manner and suppressed the expression of IL-8 and IL-1β mRNA levels.

Thiacremonone from garlic decreased lipopolysaccharide (LPS)-induced memory impairment, glial activation, proinflammatory mediators' expression and amyloidogenesis in ICR mice (Lin et al. 2012a). In an in-vitro study, similar results, with thiacremonone (1, 2 and 5 μg/mL), effectively decreased LPS (1 μg/mL)-induced glial activation and inflammatory mediator generation which are implicated in amyloidogenesis. Thiacremonone inhibited LPS-induced amyloidogenesis in cultured astrocytes and microglial BV-2 cells. NF-κB, a critical transcriptional factor regulating not only inflammation but also amyloid-β generation, was inhibited by thiacremonone via the blocking of phosphorylation of IκBα in mice brain as well as cultured astrocytes and microglial BV-2 cells. The results indicated that the anti-inflammatory compound, thiacremonone, inhibited neuroinflammation and amyloidogenesis through inhibition of NF-κB activity and thus could be applied for intervention of inflammation-related neurodegenerative disease including Alzheimer's disease.

Ethyl linoleate (ELA), isolated from the garlic cloves, downregulated inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2) expression and reduced nitric oxide (NO) and prostaglandin E2 production in lipopolysaccharide (LPS)-activated RAW 264.7 cells (Park et al. 2014). These effects were mediated by impaired translocation of nuclear factor (NF)-κB and inhibition of phosphorylation of mitogen-activated protein kinases. Further, ELA exerted its anti-inflammatory activity by inducing haeme oxygenase-1 (HO-1) expression. In lipopolysaccharide (LPS)-stimulated 3T3-L1 adipocytes, alliin was able to suppress the LPS inflammatory signals by generating an anti-inflammatory gene expression profile and by modifying adipocyte metabolic profile (Quintero-Fabián et al. 2013). Studies demonstrated that diallyl sulfide (DAS), from garlic, inhibited tumour necrosis factor-alpha (TNF-α)- and histamine-induced inflammation, suggesting that DAS might be an effective dietary agent for the prevention of oxidative stress-induced inflammation of the airway (Ho et al. 2014).

Fresh and aged black garlic extracts exhibited anti-allergic activity in-vitro (Kim et al. 2012). Markedly higher suppression of β-hexosaminidase release was found in fresh garlic extract at lower concentration compared with that of the black garlic. Aged black garlic (ABG), ethyl acetate extract (EBG) of ABG and BG10, an active fraction of EBG, suppressed the allergic response in RBL-2H3 cells, and the mechanism for its anti-allergic action may involve suppressions of release of β-hexosaminidase and TNF-α and suppression of Syk, $cPLA_2$, 5-LO and COX-2 (Yoo et al. 2014c). BG10 also significantly inhibited the passive cutaneous anaphylaxis reaction in mice. The anti-allergic actions of ABG, EBG or BG10 suggested that they may be useful as functional foods for allergic diseases.

Neuroprotective Activity

Administration of S-allylcysteine (SAC), an aged garlic constituent, prior to ischaemic insult, attenuated rat ischaemic brain damage (Numagami et al. 1996). Infarct volume and water content of both ischaemic and contralateral hemispheres were reduced by SAC, but neither allyl sulfide nor allyl disulfide was effective. Both SAC and 7-nitro indazole, a nitric oxide synthase inhibitor, did not attenuate the amount of ROS produced at the first peak, but did so in the second peak. A possible involvement of peroxynitrite, which may be formed from superoxide and nitric oxide and known to be highly toxic in ischaemia–reperfusion injury of the brain, was suggested. Dietary aged garlic extract (AGE) (2 %) and its prominent constituents, i.e. S-allylcysteine (SAC) (20 mg/kg) and diallyl disulfide (DADS) (20 mg/kg), modulated beta-amyloid precursor protein processing and tau phosphorylation in an Alzheimer's transgenic model Tg2576 (Chauhan 2006). Ameliorative effects of dietary interventions were found to be in the order of AGE > SAC > DADS.

Studies by Saleem et al. (2006) suggested that aqueous garlic extract (AGE) effectively modulated neurobehavioural and neurochemical changes in focal ischaemia, most probably by virtue of its antioxidant properties. Aged garlic extract delayed the effects of ischaemia–reperfusion-induced neuronal injury in an animal cerebral ischaemia model possibly by controlling free-radical burst induced by reperfusion, preservation of antioxidant enzyme activity and delay of other pathophysiological processes (Aguilera et al. 2010). Ray et al. (2011) found significant neuroprotective and neurorescue properties of AGE and one of its ingredients, SAC, from ROS (H_2O_2)-mediated insults to neuronal cells. Treatment of AGE and SAC were found to protect neuronal cells when they were independently co-treated with ROS. Additionally, a novel neuropreservation effect of AGE was detected in that pretreatment with AGE alone and protected ~80 % neuronal cells from ROS-mediated damage. AGE was also found to preserve presynaptic protein synaptosomal associated protein of 25 kDa (SNAP25) and synaptophysin from ROS-mediated insult in Alzheimer's amyloid precursor protein-transgenic mice. The results suggested that the neuroprotective, including preservation of presynaptic proteins by aged garlic extract and SAC, could be utilised in future drug development in Alzheimer disease. In-vivo studies suggested that the neuroprotective effect of AGE was associated not only to its antioxidant properties but also with its anti-inflammatory capacity to diminish the increase in TNF-α levels and COX-2 protein expression and activity in mouse with cerebral ischaemia (Colín-González et al. 2011). Garlic administration accompanying radiofrequency electromagnetic radiation (RF-EMR) significantly reduced advanced oxidation protein product (AOPP) levels in the brain tissue of Wistar albino rats (Avci et al. 2012). In the group for which garlic administration accompanied that of RF-EMR, there was no difference in serum NO levels compared with the RF-EMR exposed group. AGE demonstrated neuroprotective effects in rats with spinal cord injury via its antioxidant activity (Cemil et al. 2012). Aged garlic extract (AGE) and of 20 % hydroethanolic fresh extracts from garlic clove (GCE) and skin (GSE) protected against cerebral ischaemia-induced injuries in rats (Cervantes et al. 2013). The results indicated that antioxidants such as SAC present in garlic extracts may regulate ROS concentrations during ischaemia, favour pro-survival pathways and attenuate mitochondrial dysfunction.

In-vitro studies showed that aged garlic extract (AGE) and S-allylcysteine (SAC) reduced Abeta(25-35)-induced apoptosis and reactive oxygen species (ROS) generation in a rat pheochromocytoma (PC12) cell line by enhancing the endogenous antioxidant defences (Peng et al. 2002). AGE and SAC not only suppressed the generation of ROS but also attenuated caspase-3 activation, DNA fragmentation, PARP cleavage and eventually protected against Ab-induced apoptosis. S-allyl-L-cysteine (SAC) was found to selectively protect neuronal cell death induced by amyloid beta-protein (Abeta) and tunicamycin, which may be triggered by endoplasmic reticulum (ER) dysfunction in nerve growth factor-differentiated

PC12 neuronal cells (Ito et al. 2003b) and in the hippocampus, but it had no effect on neuronal cell death that was dependent upon the caspase-3-mediated pathway (Kosuge et al. 2003). Ito et al. (2003a) found that SAC and L-glutamate protected neuronal cell death in hippocampal neurons in the CA3 area and the dentate gyrus of the hippocampus induced by amyloid beta-peptide and ibotenic acid. Pérez-Severiano et al. (2004) found that SAC ameliorated quinolinate striatal toxicity in rats by its ability to scavenge free radicals, to decrease oxidative stress and to preserve the striatal activity of Cu, Zn-superoxide dismutase (Cu, Zn-SOD). SAC exerted protective effects against 3-nitropropionic acid-induced lipid peroxidation and mitochondrial dysfunction in the rat brain synaptosomes via its antioxidant properties (Pérez-De La Cruz et al. 2006). Under aggregating conditions in-vitro, SAC dose dependently inhibited Abeta fibrillation and also destabilised preformed Abeta fibrils (Gupta and Rao 2007). Further, circular dichroism and fluorescence quenching studies supported the binding ability of SAC to Abeta and inducing a partially folded conformation in Abeta. Peritoneal administration of SAC diminished cerebral ischaemia-induced mitochondrial dysfunctions in hippocampus of treated rats (Atif et al. 2009). Studies in C57BL/6J mice suggested SAC attenuated 1-methyl-4-phenylpyridinium (MPP (+))-induced neurotoxicity (Parkinsonism) in the striatum and that an antioxidant effect against oxidative stress may be partly responsible for its observed neuroprotective effects (Rojas et al. 2011). Behavioural analyses showed that SAC improved MPP(+)-induced impairment of locomotion (35 %). The protective effects of AGE and SAC were reported to be associated with antioxidant mechanisms such as scavenging of free radicals and pro-oxidant species, induction of antioxidant enzymes, activation of Nrf2 factor, inhibition of pro-oxidant enzymes and chelating effects (Colín-González et al. 2012). They also reported that SAC had ability to Nrf2 factor – a master regulator of the cellular redox state in the cerebral cortex. Studies by Ashafaq et al. (2012) suggested that SAC exhibited exuberant neuroprotective potential in the rat ischaemia–reperfusion model. SAC treatment significantly reduced ischaemic lesion volume, improved neurological deficits, combated oxidative loads and suppressed neuronal loss. The increase in glial fibrillary acidic protein and the inducible nitric oxide expression associated with focal cerebral ischaemia were markedly inhibited by the treatment with SAC. SAC significantly protected cultured rat hippocampal neurons against endoplasmic reticulum (ER) stress-induced neurotoxicity (Imai et al. 2014). It was found that the protective effects of SAC against ER stress-induced neuronal cell death were not attributable to antioxidant activity, but to the suppression of calpain (a Ca^{2+}-dependent cysteine protease) through the interaction with its Ca^{2+}-binding site.

Low concentration of diallyl disulfide (DADS) had protective effects on oxidative stress-injured neuronally differentiated PC12 cells by activating PI3K/Akt and by inhibiting GSK-3 activation, cytochrome c release, caspase-3 activation and PARP cleavage, whereas high concentration was rather cytotoxic (Koh et al. 2005). Studies showed that rats with induced ischaemia–reperfusion, pretreated with DAS, had significantly lower infarct volume the percentage of terminal dUTP nick-end labelling-positive cells than those untreated (Lin et al. 2012b). The neuroprotective effect of Das was partially attributed to its anti-apoptotic effects. Oral administration of diallyl trisulfide (DATS) beginning at clinical onset stage significantly prolonged disease duration and extended life span by about a week of SOD1-G93A transgenic mouse with amyotrophic lateral sclerosis (Guo et al. 2011). DATS treatment induced HO-1 and reduced GFAP expression in the lumbar spinal cord of SOD1-G93A transgenic mice.

Allixin, a phytoalexin of garlic and its analogue 2,6-dimethyl-3-hydroxy-4H-pyran-4-one (DHP) exhibited neurotropic activity (Moriguchi et al. 1997). Addition of allixin (1–100 ng/mL) to medium significantly promoted the survival of neurons derived from various regions of brain and increased the number of branching points per axon in hippocampal neurons. Allixin, however, was cytotoxic at higher concentrations (>1 μg/mL). Its analogue DHP

possessed potent neurotrophic activity at concentrations over 10 ng/mL without any obvious cytotoxicity up to 10 μg/mL. DHP also retained the activity to promote axonal branching. This compound may be a useful prototype leading chemical for developing therapeutic and/or prophylactic drugs for neurodegenerative disorders.

Studies demonstrated that allicin exerted neuroprotection against spinal cord ischaemia–reperfusion injury in rabbits, which may be associated with the improvement of the function of mitochondria respiratory chain complexes and inhibition of ROS production and the release of mitochondrial cytochrome c in the spinal cord (Zhu et al. 2012). In an in-vitro model of traumatic brain injury (TBI) using primary cultured rat cortical neurons, treatment with allicin significantly reduced mechanical trauma-induced lactate dehydrogenase (LDH) release and inhibited apoptotic neuronal death in a dose-dependent manner (Zhou et al. 2014b). The results demonstrated that allicin treatment may be an effective therapeutic strategy for traumatic neuronal injury and that the potential underlying mechanism involved Akt- and ERK-mediated regulation of NOS pathways. Allicin treatment (10 and 50 mg/kg, not 1 mg/kg) significantly reduced brain edema and motor functional deficits, as well as apoptotic neuronal cell death in injured cortex of rats with traumatic brain injury (Chen et al. 2014a). Further, allicin treatment decreased the expression levels of MDA and protein carbonyl, preserved the endogenous antioxidant enzyme activities and suppressed the expression of inflammatory cytokines. The results showed that allicin neuroprotective effect against traumatic brain injury was mediated via Akt/eNOS pathway-mediated anti-inflammatory and antioxidative activities. *Z*-ajoene, a major compound in oil-macerated garlic products, is protected against ischaemia–reperfusion-induced delayed neuronal death and gliosis by reducing lipid peroxidation in the gerbil hippocampal CA1 region (Yoo et al. 2014b).

Studies found that garlic oil exhibited neuroprotective effects on n-hexane-induced neurotoxicity in rats via inhibition of hepatic alcohol dehydrogenase (ADH) activity (Bi et al. 2011). The gait scores and the staying time on the rotating rod were significantly improved, the levels of malondialdehyde and ADH significantly decreased and the activities of glutathione peroxidase(GSH-Px), total antioxidation capacity and the ability of inhibition of *OH markedly increased.

Hepatoprotective Activity

Garlic bulb extract inhibited hepatic and serum glutamic-oxaloacetic transaminase, glutamic-pyruvic transaminase, lactic dehydrogenase and cholinesterase in-vitro (Bogin and Abrams 1976). The garlic extract stimulated the activity of liver adenosine triphosphatase in intact mitochondria, but had no effect on this enzyme after disruption of the mitochondria. Oral administration of garlic extract exerted a therapeutic effect on the carbon tetrachloride-intoxicated liver injury in mice (Kagawa et al. 1986). The increased conjugated diene level was diminished significantly to 82 % by the 100 mg/kg garlic extract, and also thiobarbituric acid reactivity was inhibited by all the doses of the extract. Also the high doses (100 and 500 mg) of garlic extract lowered the hepatic triglyceride and lipid contents. Marked inhibitory activity was found with garlic volatile oil, *S*-allylmercaptocysteine (ASSC) and *S*-methylmercaptocysteine (MSSC) in carbon tetrachloride (CCl_4)- and galactosamine (GalN)-induced cytotoxicity in primary cultured rat hepatocytes (Hikino et al. 1986). ASSC exhibited a remarkable inhibitory action and the volatile oil, alliin and MSSC showed tendencies to elicit protective actions in GalN-produced liver lesion in rats. The volatile oil inhibited CCL_4-induced free radical formation and lipid peroxidation, indicating that antioxidative activity participated in the inhibitory effect of the volatile oil in CCL_4-evoked liver damage.

Studies showed that diallyl sulfide (DAS) (25–100 mg/kg) completely prevented rat's liver necrosis by 1,2-dimethylhydrazine (DMH) (200 mg/kg) (Hayes et al. 1987). DAS substantially reduced macromolecular binding of [^{14}C]DMH in cultured liver cells, but had no effect on their levels of

glutathione S-transferase, glutathione reductase or glutathione peroxidase at 18 hours. The data suggested that DAS inhibited hepatocarcinogenicity by reducing the promoting influences of post-necrotic regeneration than by preventing initiation. Pretreatment of rats with garlic alone, or in combination with *Crataegus*, resulted in dose-dependent protective effects on isoprenaline-induced necroses of the heart, liver and pancreas (Ciplea and Richter 1988). The following parameters were used to evaluate the protective effect: clinical signs, qualitative histological and histoenzymatical findings, as well as quantitative microphotometric determination of enzymatic activities of succinate dehydrogenase, NADH-NBT reductase, acid phosphatase and glucose-6-phosphate dehydrogenase in cardiac, hepatic and pancreatic tissues. Intraperitoneal administration of garlic (50 mg/animal, 14 days) along with cyclophosphamide reduced the toxicity of the latter considerably with an increase in murine life span of more than 70 % (Unnikrishnan et al. 1990). The administration of garlic extract did not improve the lymphopenia produced by cyclophosphamide or liver alkaline phosphatase, but there was a significant reduction in liver glutamic-pyruvic transaminase. Moreover, garlic extract reduced the level of lipid peroxidation induced in the liver by cyclophosphamide administration.

Ajoene, a garlic-derived sulfur-containing compound, exhibited a dose-dependent (20–100 mg/kg) hepatoprotective effect against acetaminophen-induced liver injury in mice (Hattori et al. 2001). A pretreatment with ajoene suppressed the rise in serum glutamic-pyruvic transaminase activity and the reduction in the hepatic reduced glutathione level. Pretreatment by ajoene also suppressed the decrease in hepatic protein thiol content resulting from acetaminophen administration.

Studies showed that concomitant administration of garlic extracts in mice prevented arsenic-induced hepatic apoptosis by its strong antioxidant property (Flora et al. 2009). The generation of reactive oxygen species (ROS) in hepatic tissue reverted to normal values after co-administration of garlic extracts. Studies showed that cadmium-induced oxidative damage in rat liver was amenable to attenuation by pretreatment of high dose of onion and moderate dose of garlic extracts possibly via reduced lipid peroxidation and enhanced antioxidant defence system (Obioha et al. 2009). Animal studies showed that though both ascorbic acid and heated garlic juice were efficient in preventing cadmium-induced damage in the rat liver, ascorbic acid appeared to be a more powerful antioxidant than heated garlic juice in preventing cadmium-induced oxidative damage in liver, and its action may be mediated in parts via the Nrf2-Keap1 pathway (Lawal et al. 2011). Nwokocha et al. (2012) found that administration of raw garlic to rat chow offered more hepatoprotective effect to cadmium (200 ppm) followed by mercury (10 ppm) and the least protection to lead (100 ppm) administered in the drinking water to rats.

In-vivo studies showed that the combination of meso 2,3-dimercaptosuccinic acid (DMSA) and garlic extract possessed the greatest protective effect against sodium arsenite-induced hepatoxicity in rats as evidenced by low serum levels of alanine aminotransferase (ALT) and aspartate aminotransferase (AST) when compared to other treated animal groups (Hegazy and Ghaleb 2011). Studies demonstrated that diallyl disulfide (DADS) could induce the activation of HO-1/Nrf-2 pathway, which may contribute to the protective effects of DADS against ethanol-induced liver injury (Zeng et al. 2013b). DADS significantly suppressed ethanol-induced elevation of lactate dehydrogenase (LDH) and aspartate transaminase (AST) activities, decrease of glutathione (GSH) level, increase of malondialdehyde (MDA) levels and apoptosis of LO2 cells. In mice, DADS effectively suppressed acute ethanol-induced elevation of aminotransferase activities and improved liver histopathological changes.

Garlic-derived S-allylmercaptocysteine (SAMC) exhibited hepatoprotective effect in non-alcoholic fatty liver disease (NAFLD) in rats (Xiao et al. 2013). Co-treatment of SAMC attenuated NAFLD-induced liver injury, fat accumulation, collagen formation and free fatty acids (FFAs). At the molecular level, SAMC decreased the lipogenesis marker and restored the lipolysis marker. SAMC also reduced the expression levels of pro-fibrogenic factors and

diminished liver oxidative stress partly through the inhibition in the activity of cytochrome P450 2E1-dependent pathway. NAFLD-induced inflammation was also partially mitigated by SAMC treatment via reduction in the proinflammatory mediators, chemokines and suppressor of cytokine signalling. The results of studies by Ademiluyi et al. (2013) suggested that dietary inclusion of garlic powder in rats could protect against gentamicin-induced hepatotoxicity, improve antioxidant status and modulate oxidative stress, a function attributed to their phenolic constituents. In-vivo studies showed that diallyl trisulfide (DATS), the primary component of garlic, protected the rat liver from CCL_4-caused injury and fibrogenesis (Zhu et al. 2014). The hepatoprotective effect was associated with the inhibition of hepatic stellate cell activation in the rat fibrotic liver, attenuation of collagen deposition and attenuation of oxidative stress. DATS ameliorated hepatic oxidative stress by diminishing the levels of lipid peroxides and malondialdehyde and enhancing glutathione content. Oral pretreatment of diallyl disulfide (DADS) protected against carbon tetrachloride (CCl_4)-induced oxidative hepatic damage and inflammatory response in rat liver (Lee et al. 2014b). DADS increased the expression of phase II/antioxidant enzymes and simultaneously decreased the expression of inflammatory mediators in CCL_4-induced liver injury. The findings suggested that DADS induced antioxidant defence mechanism by activating the Nrf2 pathway and reducing inflammatory response by inhibiting NF-κB activation.

Renoprotective Activity

Prophylactic treatment of rats with garlic oil before the administration of ferric nitrilotriacetate (Fe-NTA), a potent nephrotoxic agent, resulted in the diminution of Fe-NTA mediated injury (Iqbal and Athar 1998). The enhancement of renal lipid peroxidation (LPO) and hydrogen peroxide generation was decreased. In addition, there was a recovery of glutathione depletion and inhibition of the activities of antioxidant enzymes. Similarly, in animals given the higher dose of garlic oil (100 mg/kg body weight), the enhanced blood urea nitrogen and serum creatinine levels, which were indicative of renal injury, showed a reduction of about 30 % and 40 %, respectively, in comparison with the group treated with Fe-NTA alone. Pretreatment with garlic oil also ameliorated the Fe-NTA-mediated induction of renal ornithine decarboxylase activity and enhancement of [3H]thymidine incorporation into DNA in a dose-dependent manner. Administration of S-allylcysteine (SAC), a garlic derivative, prevented gentamicin-induced oxidative stress and renal damage in rats (Maldonado et al. 2003). SAC ameliorated the gentamicin-induced acute renal failure by a mechanism related, partly, to its ability to decrease oxidative stress and to preserve antioxidant enzyme activity in the renal cortex. SAC treatment was able to ameliorate the increase in blood urea nitrogen (BUN) and serum creatinine and to decrease the structural damage induced by ischaemia and reperfusion in rats (Segoviano-Murillo et al. 2008). It was concluded that the antioxidant properties of SAC were involved in its protective effect on renal ischaemia and reperfusion injury. In nephrectomised rats SAC and aged garlic extract (AGE) reduced hypertension, renal damage and abundance of inducible nitric oxide synthase, 3-nitrotyrosine, poly(ADP-ribose), p22phox and gp91phox and increased SOD activity (Cruz et al. 2007). Data suggested that the antihypertensive and renoprotective effects of SAC and AGE were associated with their antioxidant properties and that they may be used to ameliorate hypertension and delay the progression of renal damage.

In another animal study, significant restoration of depleted renal glutathione and its dependent enzymes (glutathione reductase and glutathione S-transferase) was observed in diallyl sulfide (DAS)-pretreated rats (Ansar et al. 2014). DAS also attenuated Fe-NTA-induced increase in LPO, hydrogen peroxide generation and protein carbonyl formation. The results indicated that DAS may be beneficial in ameliorating the Fe-NTA-induced renal oxidative damage in rats. The study of Suru (2008) suggested against that onion and garlic extracts may exert their protective effects, cadmium-induced nephrotox-

icity, in rats via reduction in renal lipid peroxidation and enhanced antioxidant defence. While treatment with high dose of onion extract exerted a significant dose-dependent restoration of the cadmium-induced decrease in antioxidant activities, treatment with high dose of garlic elicited a pro-oxidant effect, relative to their respective low dose. In dyslipidaemic rats, interaction studies on the kidney indicated that administration of high dose of atorvastatin and garlic had a negative safety profile when compared with groups administered with low dose of atorvastatin and high dose of garlic (Reddy et al. 2010). Studies suggested that aqueous garlic extract as a supplementary to diet may have a potential therapeutic effect in delimitating the systemic oxidant effects of chronic renal failure (CRF) in rats (Deniz et al. 2011). Garlic treatment alleviated CRF-induced oxidative changes in the injured tissues, inhibited neutrophil infiltration and reduced CRF-induced elevations in the blood levels of the proinflammatory cytokines and lactate dehydrogenase. Post-administration of garlic after gentamicin treatment or co-administration of garlic and gentamicin significantly attenuated gentamicin-induced nephrotoxicity in Wistar rats (Nasri et al. 2013). Garlic had regenerative potential after tubular injury induced by gentamicin. Studies showed that aged garlic extract exhibited the ability to ameliorate kidney damage in streptozotocin-induced diabetic rats, and its renoprotective effect may be attributed to its anti-glycation and hypolipidaemic activities (Shiju et al. 2013). The efficacy of the extract was substantiated by the histopathological changes in the kidney. Administration of metformin, garlic or their combination with or after injection of gentamicin (high doses) could attenuate serum blood urea nitrogen (BUN) and creatinine in rats indicating curative and protective activity against gentamicin nephrotoxicity (Kopaei et al. 2013).

Gastroprotective Activity

Recent studies indicated that diallyl disulfide (DADS) prevented gastric mucosal damage induced by acute ethanol administration in rats and that the protective effects of DADS may be due to its potent antioxidant and anti-inflammatory activities (Lee et al. 2014a). DADS effectively suppressed the production of proinflammatory mediators induced by ethanol and prevented the formation of gastric malondialdehyde and the depletion of reduced glutathione content and restored antioxidant enzyme activities, such as catalase, glutathione peroxidase and glutathione reductase in the gastric tissues of ethanol-treated rats. Aged garlic extract (AGE) especially at 200 mg/kg protected against indomethacin (IN)-induced gastric inflammation in male rats as reflected by significant gastric mucosal healing of damage and reduction in the total microbial induced due to indomethacin administration (Badr and Al-Mulhim 2014). Further AGE normalised the significant increase in malondialdehyde (MDA), myeloperoxidase (MPO), tumour necrosis factor-α (TNF-α) values and the significant decrease in the total glutathione (tGSH), superoxide dismutase (SOD) and catalase (CAT) values induced by indomethacin.

Antihyperthyroidic Activity

The combined effects of *Trigonella foenum-graecum* and *Allium sativum* extracts at 200 and 500 mg/kg body wt., respectively, were equipotent as compared to the individual extracts in lowering the serum concentrations of serum triiodothyronine (T_3) and thyroxine (T_4) in hyperthyroidic rats and not synergistic (Tahiliani and Kar 2003). It was thus suggested that *Trigonella foenum-graecum* and *Allium sativum* extracts may be used individually and not together in the regulation of hyperthyroidism.

Diuretic and Natriuretic Activity

Intravenous administration of purified fractions of garlic (2, 4 and 6 μg/kg dry weight) to anaesthetised rabbits elicited dose-dependent diuretic–natriuretic responses which reached a maximum 60 minutes after injection and return to basal levels after 90 minutes (Pantoja et al. 1996). A gradual

decrease in heart rate, but not in arterial blood pressure, was observed during the course of the experimental periods. Further, intravenous administration of a purified garlic fraction (6 μg/ kg) to anaesthetised dogs elicited a significant biphasic diuretic and natriuretic response which reached a maximum at 180 minutes after injection (Pantoja et al. 2000). Chloride, but not potassium ions, followed the natriuretic profile. No changes were observed in arterial blood pressure or in the electrocardiogram. The purified garlic fraction also induced an inhibitory dose-dependent effect on the kidney Na, K-ATPase.

Antispasmodic Activity

Garlic juice inhibited the contractions of rabbit and guinea pig aortic rings induced by norepinephrine in Ca^{2+}-free and Ca^{2+}-containing Krebs–Henseleit solutions (Aqel et al. 1991). Also, garlic juice inhibited the contractions of rabbit and guinea pig tracheal smooth muscles induced by acetylcholine and histamine, respectively, in both Ca^{2+}-free and Ca^{2+}-containing Krebs–Henseleit solutions. Furthermore, garlic juice inhibited the spontaneous movements of rabbit jejunum and guinea pig ileum and inhibited the force of contraction of isolated rabbit hearts in a concentration-dependent manner. All inhibitions were reversible. Aqueous extracts of fresh garlic (5, 12.5, 25 and 50 mg/mL) were shown to inhibit the synthesis of the prostanoids in a dose-dependent manner (Ali et al. 1993). Fresh garlic extracts (1, 2.5, 5 and 10 mg/mL) also dose dependently inhibited spontaneous rhythmic contractions of the isolated ureter. Boiled garlic (5, 12.5, 25 and 50 mg/mL) had no effect on either ureteral motility or the prostaglandin-synthesising capacity of the sheep ureter. The addition of garlic extracts to isolated rat atria evoked negative inotropic and chronotropic effects (Radenkovic et al. 2010). Ethanolic garlic extract exerts much stronger negative inotropic (58.33 %) effects than the aqueous extract (43.66 %). Aqueous garlic extract very slightly affected the frequency, while ethanolic extract reduced it by more than 40 %. In addition to these effects, the positive inotropism and chronotropism induced by the addition of noradrenaline were much more antagonised by ethanolic garlic extract than by aqueous extract. Moreover, ethanolic garlic extract established sinus rhythm in the atria with extrasystoles induced by noradrenaline.

Studies by Grman et al. (2011) found that aqueous garlic, onion and leek extracts released nitric oxide from S-nitrosoglutathione (GSNO) in the order: garlic > onion > leek. Garlic extract (0.045 mg/mL) prolonged relaxation time of aortic rings induced by GSNO (50 nmol/L) and inhibited intracellular chloride channels. It was suggested that NO-releasing properties of the garlic, onion and leek extracts and their interaction with cysteine and glutathione were involved in NO-signalling pathway which contributed to some of its numerous beneficial biological effects.

Antilithogenic Activity

Dietary garlic and onion reduced the cholesterol gallstone incidence by 15–39 % in mice, the effect being maximum in the heat-processed onion group (Vidyashankar et al. 2009). Dietary garlic and onion markedly reduced biliary cholesterol. The cholesterol–phospholipid ratio and biliary cholesterol saturation index were reduced to 0.73–0.96 in the garlic and onion groups. Hepatic hydroxymethylglutaryl-CoA reductase activity was lowered in the lithogenic diet-fed group, while dietary garlic or onion countered this alteration and also increased the activities of hepatic cholesterol 7 alpha-hydroxylase and sterol 27-hydroxylase. Serum and liver cholesterol were decreased by feeding garlic or onion compared to the lithogenic diet. Thus, dietary *Allium* spicy garlic and onion exerted antilithogenic influence by decreasing the cholesterol hypersecretion into bile and increasing the bile acid output thus decreasing the formation of lithogenic bile in experimental mice. Apart from the beneficial modulation of biliary cholesterol saturation index, dietary garlic and onion also influenced cholesterol-nucleating and

cholesterol-antinucleating protein factors that contribute to their antilithogenic potential (Vidyashankar et al. 2010a). Dietary garlic and onion, either raw or heat processed administered for 10 weeks, regressed preformed cholesterol gallstone in mice up to 53–59 %, whereas the regression in the basal control diet group was only 10 % (Vidyashankar et al. 2010b). The antilithogenic potency of garlic was decreased by its heat processing, but not in the case of onion. Biliary cholesterol was significantly decreased in garlic- and onion-fed animals. Biliary cholesterol saturation index and hydrophobicity index were significantly lowered by dietary garlic and onion. Serum and liver cholesterol levels were decreased by feeding these spices during the post-cholesterol gallstone induction period.

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Female/Male Fertility Activity

In the Norwegian Mother and Child Cohort of 18,888 women of whom 950 (5 %) underwent spontaneous preterm delivery (PTD) (<37 gestational weeks), intake of food such as garlic with antimicrobial and prebiotic compounds may be of importance to reduce the risk of spontaneous PTD (Myhre et al. 2013). *Allium* (garlic, onion, leek and spring onion) (odds ratio (OR): 0.82) was associated with a decreased risk of spontaneous PTD. Intake of *Allium* was related to a more pronounced risk reduction in early spontaneous PTD (gestational weeks 28–31) [OR: 0.39]. The strongest association in this group was with garlic (OR: 0.47), followed by cooked onions. The strongest association with preterm prelabor rupture of membranes (PPROM) in the *Allium* group was with garlic (odds ratio: 0.74).

There are mixed views on the impact of garlic on the male reproductive system. Some studies had reported that garlic improved male sexual function with beneficial effect in the recovery of testicular functions (Hammami and El May 2013). Others reported that garlic impaired testicular functions (such as inhibition of testosterone production) and had spermicidal effect on spermatozoa.

Dixit and Joshi (1982) reported that garlic impaired testicular function. Garlic decreased body weight after treatment with a powder garlic preparation by daily gavage and caused a reduction in accessory gland weight and hypospermatogenesis. In-vitro studies showed that sperm motility was inhibited dose dependently by allitridum, from garlic, at different intervals ranging from 20 seconds to 200 minutes as compared to the control (Qian et al. 1986). Immobilisation of spermatozoa occurred at 7.5 mg/mL of allitridum. Crude aqueous garlic bulb extract exhibited instant immobilisation of the ram epididymal sperm at 0.25 g/mL and human ejaculated sperm at 0.5 g/mL (Chakrabarti et al. 2003). Sperm-immobilising effects were irreversible, and the factor of the extract responsible for immobilisation was thermostable up to 90 °C, and on boiling at 100 °C for 10 minutes, the activity was markedly reduced. Moreover, this extract was able to cause aggregation of ram sperms into small clusters after 30 minutes of incubation at 37 °C but not human spermatozoa. More than 50 % reduction in sperm viability and hypo-osmotic swelling occurred in treated sperm as compared with the controls, indicating the possibility of plasma membrane disintegration which was further supported by the significant reduction in the activity of membrane-bound 5′-nucleotidase and acrosomal acrosin. Animal studies showed that crude garlic consumption during 1 month reduced testosterone secretion, phosphatase acid activity, seminal vesicle weight and altered spermatogen-

esis at 10, 15 and 30 % doses (Hammami et al. 2008). At the higher two dosages, a significant decrease was observed in the body weight and prostate weight of male rats. Testicular histology showed a dose-dependent increase in the percentage of empty seminiferous tubules. Chronic crude garlic consumption for 2–4 months induced testicular apoptosis in Sertoli cells, germ cells and peritubular tissue including interstitial Leydig cells and myoid cells with disruption in the spermatogenesis in adult male rats (Abdelmalik 2011). Two theories were proposed: garlic being an antihypercholesterolaemic agent, it might inhibit steroidogenesis resulting in a decrease in testosterone level, and being one of the famous phytooestrogens, it possibly had direct oestrogen-like actions on adult male rat testes. Recent studies found that seminiferous tubules of rats treated with garlic fractions showed an increased number of tubules deprived of spermatozoa (Hammami et al. 2013). In addition, garlic fractions induced apoptosis of testicular germ cells and a decrease of serum testosterone levels and seminiferous tubule DNA concentrations. The results suggested that one or several garlic substances, soluble in water and precipitated by alcohol, impaired spermatogenesis.

Administration of garlic aqueous extract in the drinking water to male and female mice (100 mg/kg/day) for 3 months elicited a significant increase in the weight of seminal vesicles and epididymis of male animals as compared to controls, and the sperm count was significantly elevated (Al-Bekairi et al. 1990). There was no increase in the body weight of the test animals, and weights of the heart, liver and spleen were reduced as compared to controls. Haematological studies revealed an increase in WBC and a decrease in RBC levels of the test animals. Three-day intraperitoneal treatment (500 mg/kg) with the *A. sativum* extract failed to exhibit any oestrogenic or antioestrogenic activity. After 28 days of feeding, testosterone contents in the testis were significantly higher, and plasma corticosterone concentrations were significantly lower in rats fed with 40 and 25 % casein diets with garlic powder than in those fed with the same diets without garlic powder (Oi et al. 2001). Urinary excretion of 17-ketosteroid (an index of testosterone), nitrogen balance and hepatic arginase activity were significantly higher in rats fed with the 40 % casein diet with garlic powder than in the 40 % casein controls. In a subsequent experiment, plasma luteinising hormone concentration increased dose dependently after administration of diallyl disulfide (a garlic volatile) to anaesthetised rats. The results suggested that dietary supplementation with 0.8/100 g garlic altered hormones associated with protein anabolism by increasing testicular testosterone and decreasing plasma corticosterone in rats fed with a high protein diet.

Oral administration of onion and garlic extracts to rats successfully attenuated the adverse effects of cadmium-induced testicular damage and spermiotoxicity possibly reducing lipid peroxidation and increasing the antioxidant defence mechanism in rats (Ola-Mudathir et al. 2008). Cd caused a marked rise in testicular lipid peroxidation (LPO) and glutathione S-transferase (GST) levels and a decline in levels of glutathione (GSH), superoxide dismutase (SOD), catalase (CAT) and alkaline phosphatase (ALP). Cd intoxication significantly decreased epididymal sperm concentration and sperm progress motility and increased percent total sperm abnormalities and live/dead count. Decreases in rat body weight gain and testicular weight induced by 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) were greatly attenuated by ethanol garlic extract (Lee et al. 2009a). TCDD-induced decreases in spermatogenesis-related panels, Johnsen's score, seminiferous tubular size, ratio of tubules with sperm and sperm count/tubule were greatly improved by garlic treatment in a dose-dependent manner in the rats. TCDD-induced increases in serum cholesterol and triglyceride levels and glutamic oxaloacetate activity were also suppressed by garlic extract. The results indicated that administration of garlic to TCDD-exposed rats attenuated testicular and hepatic damage, suggesting that garlic might be a useful agent that can protect human health from toxic responses induced by environmental pollutants.

Garlic was found to be good substitute for certain nitric oxide-based market preparations for use in erectile dysfunction (Parveen et al. 2010). Garlic also had more or less similar effects and mode of action. The only step that differs was that most of the market preparations increase blood GMP (3′,5′ guanosine monophosphate) level by inhibiting its degrading enzyme phosphodiesterase-5, while garlic acted by the activation of guanylyl cyclase enzyme and thus by increasing the production of GMP in the body. Garlic could have potential as an economic, safe, easily available substitute to market preparations and unstandardised adulterated herbal formulations.

Lindane poisoning in rats was characterised by a decreased weight of testes, epididymides, prostate gland and seminal vesicles; a decrease of spermatozoa count and motility; an increased level of free thyroxin; decreased levels of TSH (thyroid-stimulating hormone) and FSH (follicle-stimulating hormone) in the serum and lindane oxidative stress as revealed by the increased level of lipid peroxidation (TBARS); an increase of superoxide dismutase activity in the testes; and a decrease of glutathione peroxidase and catalase activities in the testes and brain (Hfaiedh et al. 2011). All these lindane-induced changes were almost reversed to normal in animals injected with a garlic extract (an amount corresponding to 300 mg fresh garlic/kg/day).

Antihyperhomocysteinaemia Activity

Rats fed with AIN-93G diet devoid of folic acid exhibited mild folate deficiency and had a plasma level of total homocysteine higher than that for those fed with AIN-93G diet containing folic acid (Yeh et al. 2005). Supplementation of aged garlic extract (AGE, 4 %) to the folate-deficient L-amino acid diet of rats reduced plasma protein-bound, free and total homocysteine by 28–33 %. The supplementation did not change plasma cysteine, cysteinylglycine or glutathione concentrations. Liver concentration of *S*-adenosylmethionine was elevated by 26 %, and *S*-adenosylhomocysteine was lowered by 15 % in the AGE-supplemented group.

Cognitive Enhancement Activity

In the acute study, commercial formulation of crude garlic extract (Lasuna) (65 mg/kg, po) partially reversed the scopolamine-induced amnesia but failed to improve learning and memory in untreated animals (Mukherjee and Banerjee 2013). Chronic administration of Lasuna (40 mg/kg/day for 21 days) significantly improved learning both in control and scopolamine-induced amnesic animals. Chronic administration of Lasuna inhibited cortical acetylcholinesterase, while increasing cortical acetylcholinesterase levels. Thus the results indicated that long-term administration of crude garlic extract may improve learning and memory in mice, while the underlying mechanism of action may be attributed to the anti- acetylcholinesterase activity and antioxidant property of garlic.

Antiosteoporotic Activity

Garlic oil was found to have a positive role in suppressing ovariectomy-induced bone resorption in ovariectomised rats (Mukherjee et al. 2004). Garlic oil extract supplementation, apart from its unique influence in lowering blood cholesterol, could also prevent ovariectomy-induced low bone density, high rate of bone turnover and osteoporosis characterised by significant alteration of serum alkaline phosphatase activity, serum tartrate-resistant acid phosphatase activity, urinary excretion of calcium, phosphate, hydroxyproline and urinary calcium to creatinine ratio. Further studies in ovariectomised rat model of osteoporosis showed that 17β-oestradiol, garlic oil and lovastatin were effective in suppressing bone loss owing to oestrogen deficiency, and their efficacy in the order of lower to higher was garlic < lovastatin < 17β-oestradiol (Mukherjee et al. 2006a). The results revealed that all three compounds significantly protected the hypogonadal bone loss as reflected by higher bone densities and higher bone mineral contents than the ovariectomised group of animals. They found that in ovariectomised rat, oil extract of garlic promoted intestinal transference of calcium by

modulating the activities of both intestinal alkaline phosphatase and Ca^{2+}-activated ATPase (Mukherjee et al. 2006b). Also the observed low bone mineral content and low bone tensile strength in these rats were significantly restored by garlic oil supplementation. Further, garlic oil supplementation was able to revive partially the bilateral ovariectomy-induced decrease in the serum oestrogen titre. The garlic oil supplemented partial recovery in the serum oestrogen titre in bilaterally ovariectomised rat was found to be persistently associated with enhanced calcium transference and better preservation of bone mineral content. They also found that hypogonadism-induced oxidative stress of peritoneal macrophages and lymphocytes could be reduced by supplementation with garlic oil extract (Mukherjee et al. 2007). The hypogonadism-induced increase in the serum levels of interleukin IL-6 and TNF-α was significantly reduced by garlic oil. Further, garlic supplementation could revive the hypogonadism-induced decrease in the serum oestrogen titre and counterbalance the increase in bone turnover as determined by low bone tensile strength and alterations in bone-related biochemical variables such as urinary calcium, hydroxyproline, calcium to creatinine ratio and serum tartrate-resistant acid phosphatase activity (TRAP).

Prebiotic Activity

Garlic fructans A (DP 16, molecular weight (MW) 2,567) and B (DP 21 mw 3,345) were found to selectively stimulate the growth of beneficial *Bifidobacterium* from human intestinal microflora (Zhang et al. 2013a). The prebiotic effectiveness of garlic fructans suggested the potential for the use of garlic as a way to prevent some gastrointestinal diseases.

Wound/Wart Healing Activity

Twenty-eight patients with 2–96 warts, nine patients with 1–2 corns and a control group consisting of five patients with 7–35 warts were included in the study after obtaining a written informed consent. A study on 28 patients showed positive effect of garlic extracts in the treatment of warts and corns (Dehghani et al. 2005). With the lipid garlic extract, full recovery was achieved in all the patients with warts in 1–2 weeks, and it took 2–3 weeks for full recovery of approximately 80 % of the corns. However, for the aqueous extract, the duration of treatment, which only caused a partial recovery, was 1 month for warts and approximately 2 months for corn.

Intra-abdominal administration of *Allium sativum* (garlic) oil prevented the formation of postoperative peritoneal adhesions in the rat (Sahbaz et al. 2014). This was attributed to the anti-inflammatory, antibacterial, fibrinolytic, antithrombotic and wound healing effects of garlic, and garlic may be effective and cheap when used to prevent such adhesions in humans.

Radioprotective Activity

Hairless mice fed with 4 % aged garlic extract was protected from UVB radiation-induced suppression of contact hypersensitivity (Reeve et al. 1993). Replacing UVB with topical application of lotion containing urocanic acid, when mice were fed with a diet containing 1 % aged garlic extract, they were partially protected from *cis*-urocanic acid-induced suppression of contact hypersensitivity, with greater protection from the lower concentrations of urocanic acid. Mice fed with a diet containing 4 % aged garlic extract were protected from all the concentrations of urocanic acid. The results indicated that aged garlic extract contained an ingredient(s) that is protected from UVB-induced suppression of contact hypersensitivity and suggested that the mechanism of protection was by antagonism of the *cis*-urocanic acid mediation of this form of immunosuppression.

Diallyl sulfide (DAS) from garlic significantly inhibited nuclear aberration formation (a measure of nuclear damage) over gamma ray radiation dose range of 0.5–10 Gy in female C57BL/6J mice (Baer and Wargovich 1989) The degree of protection was related to the dose of DAS, and

the compound was ineffective if given after irradiation. Difluoromethylornithine added to the drinking water of animals 24 hours prior to and following radiation treatment abolished the ability of DAS to reduce colonic nuclear damage caused by radiation exposure. Thus DAS was protected against colonic radiation injury via a polyamine-dependent pathway.

Animal studies showed that pretreatment by gavage with freshly prepared garlic extract could lead to significant dose-related reductions in the frequencies of gamma radiation-induced (2 Gy) micronucleated polychromatic erythrocytes (Singh et al. 1995). The anticlastogenic effect of garlic extract was observed against lower radiation doses of 0.5 and 1 Gy, but not 0.25 Gy. The irradiated garlic extract-pretreated animals showed a significant reduction in sulfhydryl content and glutathione S-transferase activities. They also reported that pretreatment with garlic extract was effective in reducing gamma radiation-induced chromosomal damage in mice (Singh et al. 1996a). Against 0.25 Gy gamma radiation, a high dose of 500 mg/kg bw garlic extract was required to significantly reduce the chromosomal damage. All the three doses of garlic extract were effective in exerting a protective effect against 0.5, 1.0 and 2.0 Gy gamma radiation. S-allylcysteine sulfoxide (SAC), of garlic, was found to show significant radioprotective effect in albino rats irradiated with 400 rads of irradiation by cobalt 60 source (Jaiswal and Bordia 1996). It markedly reduced the radiation-induced mortality and showed significant protection against the tissue damaging effects of irradiation in the histopathological sections of the liver and lung. Studies in H22 tumour xenograft mice model showed that garlic oil did not increase the tumour inhibitory rate of cyclophosphamide/radiation, which indicated that garlic oil could not enhance the chemo/radiosensitivity of cancer cells (Zeng et al. 2013a). However, the decrease of the peripheral total white blood cell (WBC) count induced by cyclophosphamide/radiation was significantly suppressed by garlic oil co-treatment. Further, garlic oil co-treatment significantly inhibited the decrease of the DNA contents and the micronuclei ratio of the bone marrow and reduction of the endogenous spleen colonies induced by CTX/radiation. The findings supported the idea that garlic oil consumption may benefit for the cancer patients receiving chemotherapy or radiotherapy.

Antihypoxic Activity

Aqueous and methanolic garlic extracts exhibited dose-dependent antihypoxic effect in mice (Hosseinzadeh and Sadati 2003). The minimum effective doses of aqueous and methanolic extracts were 0.2 g/kg and 5.12 g/kg, respectively. The high doses of aqueous (16.9 g/kg) and methanolic (12.8 g/kg) extracts increased survival time up to 73.17 and 68.41, respectively.

Anti-anaemic Activity

Administration of aged garlic extract (AGE) (5 mL/day for 4 weeks) to five patients with sickle cell anaemia caused a decline in the number of Heinz body suggesting a significant antioxidant activity of AGE on sickle red blood cells (Takasu et al. 2002, 2006).

Haemolytic Activity

The degree of haemolysis of albino Wistar rat erythrocyte was greater in the treatment group compared to the control, and the percentage haemolysis was greater in blood samples with onion and garlic compared to the onion alone group (Salami et al. 2012). The same observation was made in the in-vitro study, but the degree of haemolysis was significantly higher in in-vitro than in the in-vivo experiments. It was concluded that onion and garlic increase the osmotic fragility of red blood cells in albino rats.

Antiurotoxic Activity

Pretreatment of rats with diallyl disulfide (DADS) significantly attenuated the cyclophosphamide-induced urotoxic effects, including oxidative

damage, histopathological lesions, apoptotic changes and accumulation of acrolein–protein adducts in the bladder (Kim et al. 2014). DADS also significantly increased expression of cytochrome CYP2B1/2, CYP3A1, Nrf-2, NQO-1 and HO-1 and significantly decreased expression of CYP2C11. The protective effects of DADS may be due to its ability to decrease metabolic activation of cyclophosphamide by inhibiting CYP2C11 and inducing CYP3A1, and its potent antioxidant activity and antiapoptotic effects occurred via the Nrf2-antioxidant response element pathway.

Anti-ototoxic Activity

A garlic-supplemented diet appeared to attenuate gentamicin-induced hearing loss in male Wistar rats and may be beneficial in the prevention of ototoxicity (Uzun et al. 2012).

Protective Effects Against Chemical Toxicity

Oral administration of garlic extract at three 100 (low), 200 (medium) and 400 mg (high) per kg body weight to rats was found to reduce lead concentration considerably in the liver, kidney, brain and bone indicating the potential therapeutic activity of garlic against lead (Senapati et al. 2001). Studies found that separate administration of garlic juice and ascorbic acid during pregnancy and lactation may protect lead-induced neural damage in rat offspring hippocampus (Sadeghi et al. 2013). In a comparative study on the therapeutic effects of garlic and compared with d-penicillamine in 117 car battery workers with chronic lead poisoning, clinical improvement was significant in a number of clinical manifestations including irritability, headache, decreased deep tendon reflex and mean systolic blood pressure after treatment with garlic, but not d-penicillamine (Kianoush et al. 2012). Blood lead levels were reduced significantly in the garlic and d-penicillamine groups, with no significant difference between the two groups. The frequency of the side effects was significantly higher in d-penicillamine than in the garlic group. Thus, garlic appeared safer clinically and as effective as d-penicillamine.

Aqueous garlic extract (2 mg/mL) co-administered with 10 μM $NaAsO_2$-attenuated arsenite-induced cytotoxicity reduced intracellular reactive oxygen species (ROS) level in human malignant melanoma cells (A375), human keratinocyte cells (HaCaT) and cultured human normal dermal fibroblast cells (Chowdhury et al. 2008). In addition garlic extract application in $NaAsO_2$-intoxicated Sprague–Dawley rats resulted in a marked inhibition of tissue lipid peroxide generation and enhanced level of total tissue sulfhydryl groups and glutathione and also increased the activities of antioxidant enzymes, superoxide dismutase and catalase to near normal. An increase in blood ROS level and myeloperoxidase activity in arsenic-intoxicated rats was effectively prevented by garlic administration. Garlic extract was also able to counter arsenic-mediated incongruity in blood haematological variables and glucose level. The restorative property of garlic extract was attributed to its antioxidant activity, chelating efficacy and/or oxidising capability of trivalent arsenic to its less toxic pentavalent form. The results indicated that garlic extract could be a potential protective regimen for arsenic-mediated toxicity.

Nitrate-induced toxicity in male mice was characterised by a significant decline in total erythrocyte count, total leucocyte count, neutrophil content, haemoglobin concentration, lymphocyte and monocyte content, viability of macrophage, phagocytic index and immunoglobulin level and plaque count; a significant escalation in thiobarbituric acid reactive substances level, aspartate transaminase, alanine transaminase, acid phosphatase and alkaline phosphatase; and depletion in reduced glutathione content and antioxidant enzymes, namely, superoxide dismutase and catalase in the kidney and brain (Sharma et al. 2010). Oral administration of garlic extracts to lead nitrate-treated rats attenuated the above deranged haematological, biochemical and immunological parameters to some extent.

Enzyme Inhibitory Activity

Garlic extract had been reported to inhibit urease and succinic dehydrogenase enzymes (Szymona 1952). Allicin, a major compound of garlic, had been reported to inhibit urease (Agarwala et al. 1952) and papain and amylase (Rao et al. 1946). Aqueous crushed garlic extract inhibited succinic oxidase and urease, but trypsin, amylase and lipase were unaffected (Wills 1956). Enzyme inhibitory effects observed with garlic extracts were attributed to allicin. Enzymes inhibited by allicin included succinic dehydrogenase, urease, papain, xanthine oxidase (cream), xanthine oxidase (liver), choline oxidase, hexokinase, cholinesterase, glyoxalase, triose phosphatase dehydrogenase, alcohol dehydrogenase, lactic dehydrogenase tyrosinase and alkaline phosphatase; enzymes unaffected include cytochrome oxidase, lipase, rennin, pepsin, trypsin, invertase, α-amylase, esterase (serum), D-amino acid oxidase, ascorbic acid oxidase, catalase, carbonic anhydrase, carboxylase, β-amylase and adenosine triphosphatase (Wills 1956). Enzymes strongly inhibited by allicin were succinic dehydrogenase, triose phosphatase dehydrogenase and xanthine oxidase (in cream). Alliin did not inhibit the enzymes tested. Also, yeast fermentation of glucose, respiration of yeast in the presence of glucose and endogenous respiration of rat-liver homogenate and rat muscle homogenate were all inhibited by allicin but unaffected by alliin. Garlic bulb extract was shown to inhibit hepatic and serum glutamic-oxaloacetic transaminase, glutamic-pyruvic transaminase, lactic dehydrogenase and cholinesterase in-vitro (Bogin and Abrams 1976). The extract stimulated the activity of liver adenosine triphosphatase in intact mitochondria, but had no effect on this enzyme after disruption of the mitochondria. Allicin was shown to be a specific inhibitor of the acetyl-CoA synthetases from plants, bacteria, yeast and mammals (Focke et al. 1990). The bacterial acetyl-CoA-forming system, consisting of acetate kinase and phosphotransacetylase, was also inhibited. A concentration-dependent inhibition of 3-hydroxy-3-methylglutaryl-CoA (HMG-CoA) reductase was found on the preincubation of microsomal preparations with diallyl disulfide, a component of garlic oil (Kumar et al. 1991). The garlic-derived diallyl disulfide was the most effective among the sulfides tested for the inhibition of HMG-CoA reductase.

Oral administration of garlic to lactating Swiss albino mice for 14 or 21 days postpartum was found to differentially impact on hepatic xenobiotic-metabolising enzymes in the F_1 generation mouse pups (Chharbra and Rao 1994). Cytochrome b_5 content was not affected with garlic treatment in dams and most of the pups but increased in the 14-day-old female pup translactationally exposed to the higher dose of garlic. Hepatic cytochrome P450 content and glutathione S-transferase activity remained unchanged in dams and pups exposed to garlic. Glutathione reductase decreased significantly in the liver of dams which received the lower garlic dose for 14 or 21 days and in the 21-day-old pups. Glutathione peroxidase activity decreased in dams and pups which were exposed to 400 mg garlic/kg bw for 21 days.

In acetone-treated adult male Sprague–Dawley rats, the activity of p-nitrophenol (pNP) hydroxylase was significantly decreased by all garlic compounds (diallyl sulfide (DAS), diallyl disulfide (DADS) and allyl methyl sulfide (AMS)), whereas benzphetamine N-demethylase and ethoxyresorufin O-deethylase activities were not changed (Reicks and Crankshaw 1996). The activity of pNP hydroxylase was decreased to 31 %, 54 % and 65 % of control activity, and immunodetectable CYP2E1 protein levels were decreased in a similar manner by DAS, DADS and AMS, respectively. Also, pNP hydroxylase activity was decreased to 73 %, 78 % and 67 % of control levels by DAS, DADS and AMS, respectively. DAS treatment of male Sprague–Dawley rats decreased hepatic catalase activity (Chen et al. 1999). DAS treatments resulted in the corresponding decreases in the liver catalase protein level. No significant change in the catalase activity in the kidney, lung and brain was observed with the treatments, but a slight decrease in the heart catalase activity was observed. These treatments did not cause significant changes in superoxide dismutase and glutathione peroxidase

activities in these tissues. Treatment of rats with fresh garlic homogenates (2 or 4 g/kg, i.g., daily for 7 days) caused a 35 % decrease in liver catalase activity. A/J mice treated with DAS and garlic homogenates also showed a decrease in the liver catalase activity. Diallyl sulfone (DASO2), a DAS metabolite, however, did not effectively decrease catalase activity in mice.

Nuclei Acid Activity

Feeding male albino rats with low and medium dose (1 and 2 mL/kg body weight) of garlic produced significant increase in DNA and RNA levels, but when rats were fed with 4 mL/kg body weight of garlic extract, a significant decrease in DNA and RNA levels was observed (Srivastava and Pathak 2012). It was concluded that garlic may be a building block of nucleic acids at a proper dose and time period.

Antiparasitic Activity

In-Vitro Studies

Whole garlic extract and some of its components exhibited antigiardial activity against the microaerophilic flagellate *Giardia intestinalis* (Harris et al. 2000). Whole garlic extract gave an IC_{50} at 24 hours of 0.3 mg/mL, and allyl alcohol and allyl mercaptan had IC_{50} values of 7 μg/mL and 37 μg/mL, respectively. Whole, freeze-dried garlic and *Allium*-derived compounds had an inhibitory effect on gas metabolism, exponential growth rate and final growth yield of the flagellated parasite *Spironucleus vortens* in Keister's modified TY-I-S33 culture medium (Millet et al. 2011). Of all the *Allium*-derived compounds tested, the ajoene-free mixture of dithiins and thiosulfinates were the most effective with a minimum inhibitory concentration (MIC) of 107 μg/mL and an inhibitory concentration at 50 % (IC_{50}) of 58 μg/mL. It was followed by ajoene (MIC = 83 μg/mL, IC_{50}) = 56 μg/mL) and raw garlic (MIC >20 mg/mL, IC_{50}) = 7.9 mg/mL), allicin being significantly less potent with an MIC and IC_{50} above 160 μg/mL.

Animal Studies

Diallyl sulfide, a flavour component from garlic, attenuated lipid peroxidation in mice infected with *Trichinella spiralis* (Grudzinski et al. 2001). Diallyl sulfide decreased TBARS thiobarbituric acid reactive substances (TBARS) but did not have any effect(s) on the total antioxidant status of blood in *Trichinella*-infected mice. The results suggested that diallyl sulfide may be an effective antioxidant candidate and may play a significant role in the defence against lipid peroxidation in trichinellosis. Studies demonstrated that after administration of Alchinal (a complex preparation of *Echinacea purpurea*, garlic and cocoa), the number of adult forms (10 dpi – days postinfection) of *Trichinella spiralis* and muscular larvae (36 dpi) significantly decreased in infected mice (Bany et al. 2003). Results of studies indicated that garlic may be a promising phytotherapeutic agent for the protection against trichomoniasis caused by *Trichomonas gallinae* in pigeons (Seddiek et al. 2014). Pigeons protected with aqueous garlic extract showed increased body weight and reduced mortality percentage.

Ajoene inhibited the proliferation of both epimastigotes and amastigotes of *Trypanosoma cruzi*, the causative agent of Chagas' disease (Urbina et al. 1993). Concomitant with the antiproliferative effects was the alteration of the phospholipid composition of the treated cells and inhibition of phosphatidylcholine and neutral lipid biosynthesis in particular of sterols in the epimastigotes. Diallyl trisulfide (DATS) from garlic exhibited antiparasitic activity in-vitro against human and animal protozoan parasites (Lun et al. 1994). The IC_{50} values for *Trypanosoma brucei brucei*, *Trypanosoma brucei rhodesiense*, *Trypanosoma brucei gambiense*, *Trypanosoma evansi*, *Trypanosoma congolense* and *Trypanosoma equiperdum* were in the range of 0.8–5.5 μg/mL. IC_{50} values were 59 μg/mL for *Entamoeba histolytica* and 14 μg/mL for *Giardia lamblia*. Ajoene was found to be an inhibitor and a substrate of human glutathione reductase (GR) and *Trypanosoma cruzi* trypanothione reductase (Gallwitz et al. 1999). The antiparasitic and cytostatic actions of ajoene were found to be partly

due to the multiple effects on key enzymes of the antioxidant thiol metabolism. Allicin and its derivatives were found to be cysteine protease inhibitors with antiparasitic activity (Waag et al. 2010). The compounds inhibited the CAC1 cysteine proteases falcipain 2, rhodesain, cathepsin B and cathepsin L in the low μmolar range. Some showed potent antiparasitic activity against *Plasmodium falciparum* and *Trypanosoma brucei brucei*.

Ajoene showed a potent leishmanicidal activity in-vitro against *Leishmania mexicana*, *Leishmania mexicana venezuelensis*, *Leishmania mexicana amazonensis* and *Leishmania donovani chagasi* (Ledezma et al. 2002). Concentrations higher than 0.3 μM led to total inhibition of growth, and 10 μM induced 100 % lysis of *Leishmania* after 96 hours of incubation in a chemically defined culture medium. The 50 % inhibitory concentration (IC_{50}) for lysis, for all species, was about 2 μM. The effect was dose dependent, and a threefold increase in concentration (30 μM) produced 100 % lysis of cultured forms after 72 hours. Intraperitoneal injection of garlic extract (20 mg/kg) or its protein fraction (0.04 mg/kg) to BALB/c mice augmented engulfment and destruction of intracellular amastigotes of *Leishmania major* by macrophages (Ghazanfari et al. 2006). A single dose of 20 mg/kg garlic extract intraperitoneally (i.p.) altered the number of peritoneal macrophages for at least 2 weeks. Garlic extract reduced footpad lesions in *Leishmania mexicana*-infected BALB/c mice by inducing IFN-γ production from T cells (Gamboa-León et al. 2007). In-vitro, garlic extract reduced macrophage infection through the induction of nitric oxide (NO) production. A 10- to 14-kDa fraction was identified as responsible for the in-vitro effect of the whole extract. Garlic extract exhibited higher leishmanicidal activity against *Leishmania major* (IC_{50} 34.22 μg/mL) and *Leishmania donovani* (IC_{50} 37.41 μg/mL) than pentostam (Wabwoba et al. 2010). However, the activity was significantly lower than that of amphotericin B against both the species. At a concentration of 250 μg/mL, the extract induced the production of 60 μM of nitric oxide, a tenfold upregulation in activated macrophages. The multiplication indices for *L. major* amastigotes treated in 100 μg/mL were significantly different. Treatment with the extract, daily for 28 days, led to a significant reduction in footpad swelling in BALB/c mice; similar activity is noticed in the treatment with standard drugs. Studies showed that the mixture of *Tridax procumbens* and *A. sativum* extracts was more effective in controlling *Leishmania mexicana* infection while not being toxic when tested in the acute oral toxicity assay in mice (Gamboa-Leon et al. 2014). An increase in the ratio of IgG2a/IgG1 immunoglobulins indicated a tendency to raise a Th1-type immune response in mice treated with the mixture.

Feeding *Biomphalaria alexandrina* with onion and garlic powder separately exerted some biological and biochemical changes that reduced the snails' fecundity that in turn disturbed the life cycle of *Schistosoma mansoni* parasite (Mantawy 2001: Mantawy and Mahmoud 2002). Glucose and glycogen were decreased significantly after feeding on onion and garlic. Also phenol oxidase activity was highly significantly decreased after 2 and 7 days of feeding on garlic, while feeding on onion decreased the activity of the enzyme at all periods. Alkaline phosphatase was highly significantly reduced in the haemolymph of snails that fed on either onion or garlic. Also, alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were highly significantly reduced in the haemolymph of snails that were fed on onion, while those fed on garlic showed no change in ALT activity and a high significant increase in AST activity. Total proteins were significantly decreased in the haemolymph of all treated snails, whereas variations in free amino acid contents were also observed. In another study, administration of onion and garlic extract individually and mixed either with or without the currently used drug, praziquantel, to *Schistosoma mansoni*-infected mice significantly reduced parasite burden, hepatic and intestinal eggs and oogram count (Mantawy et al. 2011). The extracts ameliorated the increase in IgM, IgG, interleukins 2 and 6 (IL-2 and 6) and tumour necrosis factor (TNF-α) and catalase enzyme, accompanied with a decrease in GPX and SOD antioxidant enzyme

activities caused by the parasite. Results of in-vitro studies indicated their strong biocidal effects against all stages of *Schistosoma mansoni* miracidia, schistosomula, cercaria and adult worms and also showed a scavenging inhibitory effect on 2,2-diphenyl-1-picrylhydrazyl (DPPH) and nitric oxide (NO) (Mantawy et al. 2012). Allicin exhibited antiparasitic activity against adult *Schistosoma mansoni* worms (Lima et al. 2011). A concentration of 5 mg/mL caused wrinkling in the tegument; a concentration of 10 mg/mL resulted in changes to tubercles and loss or modification of spines. With 15 and 20 mg/mL, increasing damage to the tegument could be seen, such as vesicle formation and the presence of ulcers.

Animal studies demonstrated garlic to have a convenient prophylactic and promising therapeutic agent for cryptosporidial infection (Gaafar 2012). Garlic successfully eradicated the *Cryptosporidium* oocysts from stool and intestinal sections of the infected immunocompetent subgroup of mice receiving garlic 2 days before the infection. Besides, the oocysts were significantly reduced in all other infected experimental subgroups in comparison to the corresponding infected control subgroups. The intestinal sections of all subgroups received garlic before or after the infection revealed a more or less normal architecture. Reduction in the level of myeloperoxidase activity was also detected in all treated subgroups.

Allicin dose dependently inhibited the in-vitro growth of *Babesia bovis*, *Babesia bigemina*, *Babesia caballi* or *Theileria equi* with IC_{50} values of 818, 675, 470 and 742 μM, respectively (Salama et al. 2014). Moreover, allicin significantly inhibited the invasion of *B. bovis*, *B. bigemina*, *B. caballi* and *T. equi* into the host erythrocyte. In-vivo, mice treated with 30 mg/kg of allicin for 5 days significantly reduced the parasitaemia of *Babesia microti* over the period of the study. Also, combinations of diminazene aceturate with allicin synergistically potentiated its inhibitory effects in-vitro and in-vivo.

Studies indicated that garlic treatment significantly attenuated the inflammation and injury of the liver induced by the protozoan parasite *Eimeria papillata* infections in male BALB/c mice (Dkhil et al. 2011). In particular, garlic counteracted the *E. papillata*-induced loss of glutathione and the activities of catalase and superoxide dismutase. Coppi et al. (2006) found that at low concentrations, allicin was not toxic to either *Plasmodium* sporozoites or mammalian cells. At these concentrations, allicin inhibited circumsporozoite protein processing and prevented sporozoite invasion of host cells in-vitro. In-vivo, mice injected with allicin had decreased *Plasmodium* infections compared to controls. When sporozoites were treated with allicin before injection into mice, malaria infection was completely prevented. A 4-day regimen of allicin administered either orally or intravenously significantly decreased parasitaemias and increased the survival of infected mice by 10 days. Allicin was found to be active against the malarial protozoan parasite, *Plasmodium yoelii* (Feng et al. 2012). Allicin treatment of malarial-infected mice reduced parasitaemia and prolonged the survival of the host in a dose-dependent manner. This effect was at least partially due to improved host immune responses. Results showed that allicin treatment enhanced the production of proinflammatory mediators such as IFN-γ, TNF, IL-12p70 and NO. The absolute numbers of CD4+ T cells, DCs and macrophages were significantly higher in allicin-treated mice. In addition, allicin promoted the maturation of CD11c+ DCs, whereas it did not cause major changes in IL-4 and the level of anti-inflammatory cytokine IL-10.

Clinical Studies

Aqueous garlic extract 5/100 mL in two doses per day or commercial garlic preparation (0.6 mg capsules) two capsules twice/day for 3 days was found to be an effective, safe and short-duration treatment for *Hymenolepis nana* infection in ten children and *Giardia lamblia* infection in 26 children (Soffar and Mokhtar 1991).

In a study of Chinese patients with *Cryptosporidium parvum* positive in baseline stool samples and clinically significant diarrhoeal disease, twice daily administration of a high-dose garlic concentrate (‘Allicin’, 30 mg) appeared to be a feasible therapeutic regimen to consider for

HIV+ patients with CD4 counts less than 100 (Fareed et al. 1996). At 6 weeks, 10 of 16 evaluable patients continued to show a reduction in stool frequency and a further stabilisation or increase in body weight. Among the 8 patients who have remained on the high-dose allicin treatment for greater than 8 weeks, *Cryptosporidium parvum* stool exams have been repeatedly negative in four of the patients. The preparation was apparently well tolerated in a majority of patients.

Insecticidal Activity

The crude methanol garlic extract was inhibitory to mosquitoes; the LC_{50} value for the third-instar larvae was 34 ppm for *Culex peus*, 25 ppm for *Culex tarsalis*, 33 pp for *Aedes aegypti* and 62 ppm for *Aedes triseriatus* and *Aedes nigromaculis* (Amonkar and Reeves 1970). The corresponding LC_{50}s of garlic oil fraction, which was obtained from the reconstituted dehydrated garlic by steam distillation, were 2.1, 2, 5.6, 4 and 2.8 ppm. When a wide range of concentrations of the oil fraction was tested against third-instar larvae of *A. sierrensis*, a concentration of 10 ppm caused 8 % mortality and 20 ppm 54 %. The larvicidal principles of garlic were isolated and identified as diallyl disulfide and diallyl trisulfide; both compounds were fatal at 5 ppm to *Culex pipiens quinquefasciatus* (Amonkar and Banerji 1971). Garlic oil as well as the active larvacidal principle from it, viz. diallyl disulfide, inhibited significantly the synthesis of the 3rd larval instar proteins of *Culex pipiens quinquefasciatus* (George et al. 1973). The maximum reduction in incorporation was observed during the first hour of treatment. The incorporation of [^{14}C]phenylalanine was also inhibited by garlic oil, and the effect was irreversible. Aqueous extracts of garlic inhibited the hatching of *Aedes aegypti* eggs (Jarial 2001). No larvae were observed either alive or dead in the garlic extracts, suggesting that the embryos were disabled before they could escape from their eggshells as viable larvae. Ethanol garlic extract exhibited larvicidal activity against the filarial mosquito *Culex quinquefasciatus* (Kalu et al. 2010). The larval mortality was observed after 24 hour treatment. The LC_{50} values calculated for the second, third and fourth larval instars were 144.543, 165.70 and 184.18 ppm, respectively. Horseradish and garlic preparations showed also an interesting and significant insecticidal activity against larvae of *Aedes albopictus*, with LC_{50} values of 2.34 g/L and 4.48 g/L, respectively (Tedeschi et al. 2011). Crude and chloroform–methanol (1:1 v/v) extracts of *Cuminum cyminum*, *Allium sativum*, *Zingiber officinale*, *Curcuma longa* and vegetable waste (*Solanum tuberosum* germinated tuber) exhibited larvicidal activities against *Anopheles stephensi* and *Culex quinquefasciatus* mosquito larvae (Singha and Chandra 2011). Relative mortality rate of both larval mosquito species was recorded in the following sequences: *Cuminum cyminum* > *Allium sativum* > *Zingiber officinale*, *Curcuma longa* > *Solanum tuberosum* germinated tuber for crude extract, and efficacy of chloroform–methanol (1:1 v/v) extract was as follows: *Curcuma longa* > *Zingiber officinale* > *Solanum tuberosum* germinated tuber > *Cuminum cyminum* > *Allium sativum*.

Garlic oil exerted significant protection against sand fly *Phlebotomus papatasi* by topical application on the skin of volunteers being 100 % and 30 % at 0.01 % and 0.005 % dilution, respectively (Valerio and Maroli 2005). Garlic also showed antifeeding effect when tested on artificial membrane and was dose dependent, being 100 % at 0.1 %. Garlic juice exhibited insecticidal activity against two Dipteran pests *Delia radicum* and *Musca domestica* (Gareth et al. 2006). LC_{50} values recorded for *D. radicum* were eggs (7-day exposure) 0.8 %, larvae (24 hour exposure) 26.4 %, larvae (48 hour exposure) 6.8 % and adults (24 hour exposure) 0.4 %. LC_{50} values recorded for *M. domestica* were eggs (7-day exposure) 1.6 %, larvae (24 hour exposure) 10.1 %, larvae (24 hour exposure) 4.5 % and adults (24 hour exposure) 2.2 %.

Larvae of *Ixodes ricinus* tick were killed in 25 minutes when exposed to garlic bulb vapour (Olenev 1950). Garlic extract was found to be effective in controlling red mite *Dermanyssus gallinae* infestation in a layer farm in Babol, north Iran (Faghihzadeh Gorji et al. 2014).

Ninety-six percent control was achieved after two successive sprays. Crude garlic extracts caused 100 % mortality of adult goat lice *Damalinia caprae* at a concentration of 100 mg/mL at 32 hour postexposure, whereas at 50 mg/mL, the same mortality was observed at 48 hour postexposure (Lakshmanan et al. 2013).

Dichloromethane (DCM) extract of *A. sativum* was found to have anti-tick activity (Nchu et al. 2005). In the Type A contact toxicity bioassay, DCM garlic extract demonstrated a high acaricidal bioactivity against *Hyalomma marginatum rufipes* with 100 % of ticks killed in less than an hour, and toxicity persisted to the second day. A weak acaricidal activity of aqueous extracts of *A. sativum* was observed in the Type B contact toxicity bioassay. In the Type C contact toxicity bioassay, a concentration of 24 % w/v of DCM extracts of garlic in sunflower oil killed 100 % of *Hyalomma marginatum rufipes* (LC_{50} = 5.9 % w/v) and *Rhipicephalus pulchellus* (LC_{50} = 10.3 % w/v) by 24 hours posttreatment of ticks. Garlic and onion oils exerted acaricidal effect on all stages of *Boophilus annulatus* hard tick at concentrations higher than 5 % (Aboelhadid et al. 2013). Only garlic oil could kill 100 % of adult ticks at concentrations from 5 % in alcohols. Studies showed that both Mexican oregano and garlic essential oils had very similar activity, producing high mortality (90–100 %) in all tested concentrations on 10-day-old *Rhipicephalus* (*Boophilus*) *microplus* tick larvae (Martinez-Velazquez et al. 2011). Crude extracts of garlic cloves and papaya seeds were found to have very good acaricidal properties and could be a potential component of alternative *Rhipicephalus* (*Boophilus*) *microplus* cattle tick control strategy (Shyma et al. 2014). Garlic cloves and papaya seed extract produced complete failure of eclosion of eggs from the treated ticks even at lower concentrations and induced significant larval mortality.

Molluscicidal Activity

Aqueous garlic extract exhibited high molluscicidal activity against the snail *Lymnaea acuminata* (Singh and Singh 1993). Allicin (allyl 2-propenethiosulfinate) was identified as the active moiety in garlic causing death of snails *Lymnaea acuminata* and *Indoplanorbis exustus* (Singh and Singh 1995). Allicin inhibited the activity of acetylcholinesterase (AChE), lactic dehydrogenase (LDH) and alkaline phosphatase (AP) in in-vivo and in-vitro exposure against *Lymnaea acuminata* (Singh and Singh 1996a). It was observed that succinic dehydrogenase activity in the nervous tissue of *Lymnaea acuminata* was increased in in-vivo treatment, whereas with in-vitro exposure, allicin caused no significant change in succinic dehydrogenase activity. The inhibition kinetics of these enzymes indicates that allicin caused an uncompetitive inhibition of AChE and a competitive inhibition of LDH and alkaline phosphatase. The increase in 24 hour toxicity of garlic bulbs harvested from the 2nd to the 11th month after sowing, against *Lymnaea acuminata*, was 48.33 times, whereas against *Indoplanorbis exustus* it was 24 times (Singh and Singh 1996b). Both piperonyl butoxide and MGK-264 enhanced the toxicity of *Azadirachta indica*, a powdered extract of *Allium sativum* bulbs and an oleoresin of *Zingiber officinale* rhizomes against the snails *Lymnaea acuminata* and *Indoplanorbis exustus* (Singh et al. 1998). The response of snails to the synergised mixtures was both time and dose dependent. *Allium sativum* bulb powder and its binary combination with *Cedrus deodara* oil significantly reduced fecundity, egg viability and survival of the terrestrial snail *Achatina fulica* within 15 days (Rao and Singh 2000). Discontinuation of the treatments after day 30 did not lead to a recovery trend in the next 30 days. Day 0 sublethal treatment of all the molluscicides caused a maximum reduction in protein, amino acid, DNA, RNA and phospholipid levels and simultaneous increase in lipid peroxidation in the ovotestis of treated *A. fulica*. The binary treatment of *Cedrus deodara* oil and *Allium sativum* bulb powder was found to be toxic to *Achatina fulica* than single treatment (Rao and Singh 2002). This combination treatment was found to be effective than single treatment against AChE, LDH and AP in the nervous tissue of the snail (Rao et al. 2003).

It was observed that the combination of plant-derived molluscicide *Polianthes tuberosa*, *Trachyspermum ammi* and *Allium sativum* powder; *Azadirachta indica* oil; and oleoresin of *Zingiber officinale* and their active molluscicidal components, viz. tigogenin, hecogenin, azadirachtin, allicin, thymol and [6]-gingerol in combination with MGK-264 or piperonyl butoxide, caused a significant reduction in fecundity, hatchability and survival of young snails of *Lymnaea acuminata* (Singh and Singh 2000a). The plant-derived molluscicides *Azadirachta indica* oil, *Allium sativum* powder and oleoresin of *Zingiber officinale* rhizome and their active molluscicidal components, azadirachtin, allicin and [6]-gingerol, alone or in combination (1 + 5) with piperonyl butoxide (PB) or ENT 8184 (MGK-264), caused a significant reduction in the activity of acetylcholinesterase, lactic dehydrogenase, acid and alkaline phosphatases and sodium–potassium ATPase in the nervous tissue of *Lymnaea acuminata* (Singh and Singh 2000b). There was a significant increase in the activity of succinic dehydrogenase. In-vivo exposure for 24 hours to sublethal concentrations of azadirachtin, allicin and [6]-gingerol, singly and with PB or ENT 8184, significantly altered the dopamine and 5-hydroxytryptamine levels in the nervous tissue of *L. acuminata*. It was concluded that these active moieties singly or with PB or ENT 8184 adversely affect all known neurotransmission mechanisms in the snail, either separately or through a complex interaction between the different neurotransmitters.

Effects of sublethal treatment (20 and 60 % of LC_{50} at 24 hours) of the plant-derived molluscicides *Annona squamosa* and *Lawsonia inermis* and their combinations with other herbal molluscicides, such as *Cedrus deodara*, *Azadirachta indica*, bulb powder of *Allium sativum* and *Polianthes tuberosa*, and oleoresin of *Zingiber officinale* and acetogenins extracted from the seeds of *A. squamosa* were toxic to the snail *Lymnaea acuminata* (Singh and Singh 2004). It was observed that the plant-derived molluscicides are singly and in binary combinations with other herbal molluscicides, and the extracted acetogenins caused a significant reduction in the fecundity, hatchability and survival of young snails.

Anthelmintic Activity

Garlic may be useful as an alternative treatment against nematode parasites in animals and humans (Ayaz et al. 2008). Freshly crushed garlic homogenate administered orally eight times was 78.03 % effective against the nematode *Aspiculuris tetraptera* in naturally infected mice. Ivermectin was 91.24 % effective. Administration of raw garlic mixed with food daily for 5 days to a man infected with the hookworm, *Necator americanus*, and a young dog infected with *Ancylostoma caninum* elicited a significant reduction in the number of larvae of both species in faecal cultures made during the period of garlic ingestion (Bastidas 1969). Dead eggs were found in the faecal cultures. However there was no evidence of garlic effect on the output of eggs of both species. Garlic essential oil produced significant reduction in the frequency and the amplitude of the spontaneous muscular activity of whole fluke *Fasciola gigantica* at 1 and 3 mg/mL concentrations (Singh et al. 2009). It caused complete paralysis of the fluke after 15 minutes of administration of 3 mg/mL concentration. Similar to whole fluke, essential oil of *A. sativum* (3 mg/mL) also produced flaccid paralysis in the strip preparations of the flukes.

Ethanol extracts of six plant species including *Allium sativum* exhibited anthelmintic activity in-vitro against *Haemonchus contortus* from sheep (Ahmed et al. 2013).

Garlic/Drug Interaction Activity and Metabolising Enzymes

Garlic phytochemicals and garlic supplements can influence the pharmacokinetic and pharmacodynamic behaviour of concomitantly ingested drugs by various mechanisms including enzyme inhibition/activation (cytochrome P450, glutathione *S*-transferase, glucuronyl transferase),

P-glycoprotein (Pgp) activation or inhibition, altered Pgp expression and membrane fluidity (influx, efflux, passive diffusion) and modulated drug solubility and uptake (Berginc and Kristl 2013). Garlic phytochemicals from aged garlic extract modified the activities of secretory and absorptive transporters in both the intestine and liver and competitively inhibited CYP3A4 enzyme. The increased activities of the most important intestinal efflux (P-glycoprotein – Pgp, multidrug resistance-associated protein 2 – MRP-2, breast cancer resistance protein – BCRP) and uptake (monocarboxylate transporter 1 – MCT1, organic anion-transporting polypeptide – OATP, peptide transporter 1 – PepT1) transporters were caused by changes in the electrophysiological membrane properties and by allosteric modifications.

Aged garlic extract (AGE) was found to enhance P-glycoprotein (Pgp) and multidrug resistance-associated protein 2-mediated effluxes through rat jejunum of marker substrates rhodamine 123 and 2,4-dinitrophenyl-*S*-glutathione, respectively (Berginc et al. 2009). In contrast rhodamine 123 efflux through the Caco-2 cell monolayers was not altered by aged garlic extract, whereas the efflux of 2,4-dinitrophenyl-S-glutathione increased significantly. So altered activity of the important transport proteins could significantly change the pharmacokinetic properties of conventional medicines taken concomitantly with aged garlic extract. Increased activities of secretory (Pgp, multidrug resistance-associated protein 2) and absorptive (monocarboxylate transporter 1, organic anion-transporting polypeptide) transporters involved in drug absorption were observed in the rat small intestine and Caco-2 cell monolayers in the presence of AGE (Berginc et al. 2010c). Transport of drugs mediated by breast cancer resistance protein and H(+)-oligopeptide transporter 1 was activated in rat intestine but was inhibited through Caco-2 cells. Passive membrane permeability of tested compounds remained unaltered through the rat small intestine, while significant changes were observed with Caco-2 cell monolayers. Aged garlic extract significantly inhibited saquinavir efflux from rat hepatocytes, while the efflux of darunavir significantly increased (Berginc et al. 2010a). Garlic phytochemicals inducing the distribution changes of saquinavir and darunavir were most probably flavonoids and lipophilic organosulfur compounds, respectively. All tested phytochemicals (except *S*-allyl L-cysteine) and aged garlic extract inhibited CYP3A4 metabolism of both drugs and modulated hepatic distribution of the corresponding saquinavir and darunavir metabolites The fractions of tested anti-HIV drugs absorbed could decrease significantly during self-medication with garlic supplements or ritonavir dose adjustments (Berginc et al. 2010b). Due to distinct saquinavir and darunavir preferences for binding sites on efflux transporters, the presence of other compounds (garlic phytochemicals, ritonavir), capable of influencing intestinal transporter-enzyme interplay, might lead to pharmacokinetic interactions during concomitant consumption of antiretrovirals and garlic supplements as observed in clinical studies and case reports with anti-HIV drugs.

Studies suggested that the effect of garlic oil on the hepatic drug-metabolising enzyme system was found to be dose dependent (Dalvi 1992). Adult, male Sprague–Dawley rats treated with a single dose of garlic oil (500 mg/kg i.p.) showed a significant depression of hepatic cytochrome P450, aminopyrine N-demethylase and aniline hydroxylase, while microsomal protein content, cytochrome b5, NADPH-cytochrome c reductase, benzphetamine N-demethylase and cytosolic glutathione S-transferase remained unaffected 24 hours following the treatment. In contrast, daily administration of garlic oil (50 mg/kg i.p. for 5 days) produced a significant increase in hepatic cytochrome P450, aminopyrine N-demethylase and benzphetamine N-demethylase activities, but not in the rest of the aforementioned parameters of biotransformation reactions. Oral administration of diallyl sulfide (DAS), a garlic component, inhibited 1,2-dimethylhydrazine-induced colon and liver cancer in rats (Brady et al. 1988). The selective inhibition of activity of P450IIE1, an isoenzyme of cytochrome P450, and suppression of its level in microsomes may contribute to the reported chemoprotective effects of DAS. DAS also

inhibited N-nitrosodimethylamine (NDMA) demethylase activity in-vitro. Further studies suggested that diallyl sulfide inhibited the metabolism of cytochrome P450 2E1 substrates by competitive inhibition mechanisms and by inactivating P450 2E1 via a suicide-inhibitory action of its putative metabolites diallyl sulfoxide and diallyl sulfone (Brady et al. 1991a). They also demonstrated a time- and dose-dependent decrease of hepatic microsomal P450IIE1 activity, induction of P450IIB1 and pentoxyresorufin dealkylase activity and moderate induction of ethoxyresorufin dealkylase activity by oral DAS treatment (Brady et al. 1991b). Treatment with putative metabolites of DAS, diallyl sulfoxide and diallyl sulfone, led to similar modulations in monooxygenase activities, but the decrease of P450IIE1 activity by the sulfone occurred more rapidly. When rats were subjected to a 48 hour fast and DAS treatment, the starvation-induced microsomal P450IIE1 level was decreased by DAS. Inhibition of hepatotoxicity due to exposure to P450IIE1 substrates, CCL_4 and NDMA, by DAS was observed under a variety of treatment schedules. Studies suggested that diallyl sulfone (DASO2) selectively modulated cytochrome P450 isoenzymes in cultured rat primary hepatocytes and that the induction of P450 2B1/2 by DAS in rat liver may be mediated by its metabolite, DASO2 (Pan et al. 1993a). They further demonstrated that the induction of P450 2B1/2 in rat liver by DAS was mainly due to transcriptional activation (Pan et al. 1993b). In the DAS-treated rats, P450 2B1/2 mRNA was also markedly induced in the stomach and duodenum. DAS treatment, however, did not change the levels of P450 2B1/2 mRNA in the lung and nasal mucosa.

Diallyl disulfide (DADS) enhanced intestinal epoxide hydrolase (EH) and cytochrome P450 (P450) 2B1/2 protein levels and the activities of pentoxy- and benzyl-oxyresorufin O-dealkylases, arylhydrocarbon hydroxylase, microsomal epoxide hydrolase, p-nitrophenol UDP-glucuronyl transferase and glutathione S-transferase and decreased N-nitrosodimethylamine demethylase activity in rats (Haber et al. 1995). In the liver, DADS produced similar effects and, in addition, increased cytochrome P450 1A1/2 protein level and phenoxazone-metabolising activities (ethoxy- and methoxyresorufin O-dealkylases) and p-hydroxybiphenyl UDP-glucuronyl transferase and decreased P450 2E1 level. Low doses of DAS were found to increase tissue activities of the phase II detoxification enzymes quinone reductase and glutathione transferase in the gastrointestinal tract of the rat and may afford protection against cancer of the gastrointestinal tract (Munday and Munday 1999).

Garlic oil and its organosulfur compounds, diallyl sulfide (DAS) and diallyl disulfide (DADS), modulated the drug-metabolising (cytochrome) and antioxidant enzyme activities in rats (Sheen et al. 1999). The action of garlic oil appeared to be independent of dietary lipid content. Oral administration of rats for 6 weeks with garlic oil and its three organosulfur compounds, diallyl sulfide (DAS), diallyl disulfide (DADS) and diallyl trisulfide (DATS), exhibited a modulatory effect on rat hepatic detoxification enzyme activity and protein and mRNA expression (Wu et al. 2002). Garlic oil and DAS in significantly increased pentoxyresorufin O-dealkylase (PROD) activity is compared with that of the control rats. In contrast, N-nitrosodimethylamine demethylase activity in rats that received DADS and DATS was significantly lower than that in the control rats. To the phase II enzyme, garlic oil, DADS and DATS significantly increased the glutathione S-transferase (GST) activity towards ethacrynic acid. The protein contents of cytochrome P450 1A1, 2B1 and 3A1 were increased by garlic oil and each of three allyl sulfides, and the change among the allyl sulfides was in the order of DAS > DADS > DATS. The placental form of GST (PGST) level was also increased by garlic oil and the three allyl sulfides, but the increase among the allyl sulfides was DATS congruent with DADS > DAS. P450 2E1, however, was suppressed by each garlic component. Changes in cytochrome P450 1A1, 2B1 and 3A1 and PGST mRNA levels by garlic components were similar to those noted in the protein levels. Gastric intubation of rats with a single dose of 200 mg/kg diallyl sulfide (DAS), diallyl disulfide (DADS) and allyl methyl sulfide (AMS)

decreased hepatic CYP2E1 protein by 45 %, 25 % and 47 %, respectively (Davenport and Wargovich 2005). Daily treatment for 1, 4 and 8 weeks with 200 mg/kg DAS and AMS resulted in time-dependent increases in hepatic CYP1A1 and CYP1A2 protein levels to a maximum of 600 % and 50 % for DAS and 1,600 % and 240 % for AMS after 8 weeks. Dosing for 8 weeks with 200 mg/kg DAS, but not AMS or lower doses of DAS, induced bile duct obstruction and focal areas of necrosis. The results indicated that DAS and AMS may be beneficial in inhibiting chemically induced colon cancer, but that longer dosing with higher concentrations of DAS may elicit minor hepatic toxicity. Oral administration of garlic allyl sulfides 0.5 or 2 mmol/kg BW diallyl sulfide (DAS) or 0.5 mmol/kg BW diallyl disulfide (DADS) or diallyl trisulfide (DATS) to rats three times per week for 6 weeks differentially induced cytochrome CYP 2B1 and glutathione S-transferase expression, and this upregulation of these two biotransformation enzymes was tissue specific (Lii et al. 2006).

Chen et al. (2003) found that co-administration of garlic oil (GO) and fish oil (FO) modulated the antioxidant- and drug-metabolising capacity of rats and that the effect of both drug-metabolising enzymes was additive. Garlic oil dose dependently increased hepatic glutathione S-transferase (GST), glutathione reductase, superoxide dismutase (SOD) and ethoxyresorufin O-deethylase (EROD) activities, but decreased glutathione peroxidase and N-nitrosodimethylamine demethylase (NDMAD) activities. The high-FO group had greater SOD and EROD, NDMAD and GST activities than those fed on low or high maize (MO) oil. GO dose dependently enhanced the protein level of the Ya, Yb1 and Yc isoenzymes of GST and cytochrome P450 (CYP) 1A1 and 3A1, but GO suppressed CYP2E1 expression. Regardless of the dosage of GO, the high-FO diet increased CYP1A1, CYP3A1 and CYP2E1 levels compared with the high- and low-MO diets. Accompanying the changes observed in immunoblots, CYP1A1 and CYP3A1 mRNA levels were increased by GO in a dose-dependent manner and also increased additively in combination with FO feeding. Earlier they found that dietary fat (corn oil) and garlic oil independently modulated cytochrome P450 2B1 and glutathione (GSH) S-transferase (PGST) expression at transcriptional and/or post-transcriptional stages in the rat (Chen et al. 2001).

Exposure of immortalised human hepatocytes (Fa2N-4 cells) to increasing concentrations of garlic extract led to progressive reduction in Fa2N-4 CYP2C9 activity (Ho et al. 2010). CYP2C9 mRNA expression also revealed a concentration-dependent reduction. Greater than 90 % reduction in CYP2C9 activity was observed following 4 days of exposure to 50 μg/mL garlic extract. In contrast, exposure to garlic extract had no effect on the CYP3A4 enzymatic activity or RNA transcript concentration in Fa2N-4. Garlic peroxidase possessed a pentacoordinated haeme group with a histidine as a proximal ligand (El Ichi et al. 2011). Garlic peroxidase exhibited a high affinity for hydrogen peroxide as well as various reducing co-substrates. In addition, high enzyme specificity was demonstrated. Also, garlic peroxidase showed a great potential for the application for drug metabolism as shown by its ability to react with 1-nitrohexane in the presence of sodium dithionite.

Administration of garlic and atorvastatin to dyslipidaemic rats augmented atorvastatin maximum observed plasma concentration, half-life, area under plasma concentration-time curve (AUC) and mean resident time (Reddy et al. 2012).

In a 12-week double-blind, randomised, placebo-controlled pilot study of 48 patients on warfarin therapy who completed the study, intake of garlic extract did not increase haemorrhage (Macan et al. 2006). The results suggested garlic extract to be relatively safe and to pose no serious haemorrhagic risk for closely monitored patients on warfarin oral anticoagulation therapy.

Pharmacokinetic Studies

After consumption of onions or garlic, the methylates of N-acetyl-*S*-(2-carboxypropyl)-cysteine (1), N-acetyl-*S*-allylcysteine (2) and hexahydrohippuric acid (3) were detected in

human urine (Jandke and Spiteller 1987). The compounds 1 and 2 were metabolites of peptides introduced with onions or garlic into the body. Allicin (allyl thiosulfinate) showed a remarkable first-pass effect and passed the isolated perfused rat liver unmetabolised only at high concentrations which caused considerable cell injuries (Egen-Schwind et al. 1992b). Diallyl disulfide and allyl mercaptan were identified as metabolites of allicin and could be determined in the perfusion medium as well as in the bile and the liver tissue. Ajoenes and vinyldithiins were detected in the perfusion medium after liver passage, but no metabolites of them could be identified.

After oral administration of 27 mg 2-vinyl-4H-1,3-dithiin and 9 mg 3-vinyl-4H-1,2-dithiin to rats, both vinyldithiins could be detected in the serum, kidney and fat tissue, over a period of 24 hours, whereas in the liver only 1,3-vinyldithiin was found (Egen-Schwind et al. 1992a). Pharmacokinetic parameters (t1/2, ke, Cltot, AUC and Vd) were determined using compartment models, elucidating the different pharmacokinetic behaviour of both vinyldithiins. 1,3-Vinyldithiin appeared to be less lipophilic and was rapidly eliminated from the serum, kidney and fat tissue, whereas 1,2-vinyldithiin was more lipophilic and showed a tendency to accumulate in fat tissue. Allicin, the precursor of the vinyldithiins, was metabolised more rapidly in liver homogenate than the vinyldithiins. After oral administration of doses (8 mg/kg) of garlic constituents (alliin, allicin and vinyldithiins (2-vinyl-[4H]-1,3-dithiin and 3-vinyl-[4H]-1,2-dithiin)) in the form of an oil macerate of the 35S-labelled substance to rats, there was no detectable difference in organ distribution between 35S-allicin and the labelled vinyldithiins (Lachmann et al. 1994). All that could be established from the urinary metabolite pattern was that unchanged 35S-allicin and unchanged labelled vinyldithiins were absent. The results revealed no differences in pharmacokinetic behaviour between 35S-allicin and the labelled vinyldithiins.

The total amount of *N*-Acetyl-*S*-allyl-l-cysteine (allylmercapturic acid, ALMA) found in the urine of volunteers who consumed two garlic tablets was 0.43 mg (de Rooij et al. 1996). In the urine of the three volunteers who consumed not only two garlic tablets but also additional fresh garlic, a significantly higher amount of ALMA was excreted in the urine, 1.4 mg. The elimination half-life of ALMA, estimated from urinary excretion rate versus time curves, was 6.0 hour. Ten glutathione (GSH) conjugates were identified in the bile collected from rats dosed with diallyl sulfide (DAS), namely, *S*-[3-(*S*′-allyl-S′-dioxomercapto)-2-hydroxypropyl]glutathione (M1, M2; diastereomers), *S*-[3-(*S*′-allyl-*S*′-dioxomercapto)-2-hydroxypropyl]-glutathione (M5), *S*-[2-(*S*′-allyl-S′-dioxomercapto)-1-(hydroxymethyl) ethyl]glutathione (M3, M4; diastereomers), *S*-[3-(*S*′-allylmercapto)-2-hydroxypropyl]glutathione (M6), *S*-(3-hydroxypropyl)-glutathione (M7), *S*-(2-carboxyethyl)glutathione (M8), allyl glutathionyl disulfide (M9) and S-allylglutathione (M10) (Jin and Baillie 1997). With the exception of M6, all of the above GSH conjugates were detected in the bile of rats treated with diallyl sulfone diallyl sulfone (DASO), while only M3, M4, M5, M7, M8 and M10 were found in the bile of rats treated with DASO2.

Cycloalliin, an organosulfur compound found in garlic and onion, when administered intravenously at 50 mg/kg to rats, was rapidly eliminated from blood and excreted into urine, and its total recovery in urine was 97.8 % in 48 hours (Ichikawa et al. 2006). After oral administration, cycloalliin appeared rapidly in plasma. Orally administered cycloalliin was distributed in the heart, lung, liver, spleen and especially kidney. When administered orally at 50 mg/kg, cycloalliin was excreted into urine but not faeces. However, the total faecal excretion of (3*R*,5*S*)-5-methyl-1,4-thiazane-3-carboxylic acid was 67.3 % (value corrected for cycloalliin equivalents). In addition, no (3R,5S)-5-methyl-1,4-thiazane-3-carboxylic acid was detected in plasma (<0.1 μg/mL), and negligible amounts (1.0 %) were excreted into urine. In in-vitro experiments, cycloalliin was reduced to (3*R*,5*S*)-5-methyl-1,4-thiazane-3-carboxylic acid during anaerobic incubation with caecal contents of rats. The data indicated

that the low bioavailability (3.73 % and 9.65 % at 25 and 50 mg/kg, respectively) of cycloalliin was due mainly to reduction to (3*R*,5*S*)-5-methyl-1,4-thiazane-3-carboxylic acid by the intestinal flora and also poor absorption in the upper gastrointestinal tract.

Most of the administered allixin in mice disappeared within 2 hours, and the bioavailability of allixin in the serum was estimated to be 31 % by obtained area under the blood concentration-time curve (AUC) (Kodera et al. 2002b). Three allixin metabolites were identified having a hydroxylated pentyl group, namely, hydroxy-5-methoxy-6-methyl-2-(4-hyroxypentyl)-4H-pyran-4-one; 3-hydroxy-5-methoxy-6-methyl-2-(2-hyro xypentyl)-4H-pyran-4-one; and 3-hydroxy-5-methoxy-6-methyl-2-(1-hyroxy-pentyl)-4H-pyran-4-one.

Various components of garlic and aged garlic extract, including allicin, S-allylcysteine (SAC) and volatile metabolites of allicin, were found in breath, plasma and simulated gastric fluids (Rosen et al. 2000, 2001). Major volatile compounds such as diallyl disulfide (DADS) and diallyl sulfide (DAS) were not the major compounds found in the breath; rather, the major volatile was allyl methyl sulfide, which may have been formed from the action of glutathione on DADS and DAS or on other components containing the C_3H_5-S-moiety. Volatiles such as *p*-cymene and D-limonene were also detected in the breath especially after 1.5 hour garlic consumption. Data indicated that allicin is decomposed in stomach acid to release allyl sulfides, disulfides and other volatiles that were postulated to be metabolised by glutathione and/or S-adenosylmethionine to form allyl methyl sulfide (Rosen et al. 2000, 2001). SAC, a nonvolatile bioactive component of aged garlic preparations could be absorbed by the human body and could be determined in plasma.

Adverse Effects of Garlic

Inhalation and cutaneous absorption were reported to be common portals of entry of garlic volatiles (Buchan 1974). Habitual exposure to extremely small concentrations could cause nausea, vomiting (sudden and explosive), contact dermatitis, pharyngitis, lethargy and the tell-tale garlic breath. Acute intoxications could also produce decerebrate central nervous system phenomena with convulsions. Adverse effects of garlic that had been reported with oral ingestion, inhalation and topical exposure included smelly breath, body odour, flatulence, oesophageal and abdominal pain, small intestinal obstruction, contact dermatitis, rhinitis, asthma, bleeding, myocardial infarction, urticaria, angioedema, anaphylaxis, skin blisters and ulcero-necrotic lesions (Morbidoni et al. 2001; Singh and Singh 2008). They asserted that the causality of garlic for specific adverse effects was established for smelly breath, body odour and allergic reactions; data regarding other adverse effects were primarily based on case reports. The frequency of adverse effects of garlic and whether they vary by particular preparations were yet to be established. Case reports have highlighted the possibility that garlic use may cause allergic reactions (allergic contact dermatitis, generalised urticaria, angioedema, pemphigus, anaphylaxis and photoallergy), alteration of platelet function and coagulation (with a possible risk of bleeding) and burns (when fresh garlic is applied on the skin, particularly under occlusive dressings) (Borrelli et al. 2007). Consumption of garlic by nursing mothers modifies their infant's behaviour during breast-feeding. Finally, garlic may enhance the pharmacological effect of anticoagulants (e.g. warfarin, fluindione) and reduce the efficacy of anti-AIDS drugs (i.e. saquinavir). Garlic appeared to have no effect on drug metabolism, but patients taking anticoagulants should be cautious (Tattelman 2005). One should be prudent to stop taking high dosages of garlic 7–10 days before surgery because garlic could prolong bleeding time.

Garlic Breath

Immediately after finely grated, raw garlic ingestion, two major odour compounds allyl mercaptan and diallyl disulfide were identified in human mouth breath (Minami et al. 1989). Allyl mercaptan was the major garlic-smelling compound in

human mouth breath, and diallyl disulfide was secondary. Considerable compositional differences found in the analyses for the gas phase of garlic cloves, kept in oil, were likely associated with the poor stability of allicin in a lipophilic environment; a marked increase in the amounts of 2-propene-1-thiol, acetic acid and ethanol was observed in the gas phase, whereas trisulfides were present in traces only (Laakso et al. 1989). The occurrence of 2-propene-1-thiol and diallyl disulfide, the two principal sulfur components in exhaled air, also may indicate a rapid degradation of most garlic volatile components probably caused by the enzymatically active human salivary or digestive system. Allyl methyl sulfide, diallyl sulfide, diallyl disulfide, *p*-cymene and D-limonene were found consistently in the breath of all human subjects after ingestion of garlic (Ruiz et al. 1994). Allyl thiol was detected occasionally. Hydrogen sulfide, a potential breath odour compound, was not efficiently trapped due to its low breakthrough volume in the adsorbent resins and thus was analysed by direct injection of breath samples using sulfur-sensitive flame photometric GC. Diallyl disulfide (DADS) was found with allyl mercaptan (AM) in human breath after ingestion of dry or fresh garlic (Cai et al. 1995). Excretion of selenium as dimethyl selenide was observed in humans only in response to acute oral doses of selenium. After ingestion of raw garlic, the concentrations of allyl methyl disulfide, diallyl sulfide, diallyl disulfide and diallyl trisulfide reached a maximum and declined to baseline values within the next 2–3 hours in the breath of a test person (Taucher et al. 1996). Concentrations of allyl methyl sulfide, dimethyl sulfide and acetone increased much more slowly and showed enhanced values even 30 hours after garlic consumption. The strong increase of the concentration of acetone might be indicative of enhanced metabolism of serum cholesterol, triglycerides and total lipids in the bloodstream. Low-molecular sulfur compounds (LMSC), namely, allyl mercaptan, methyl mercaptan and allyl methyl sulfide, were detected in significant amounts in human breath after garlic ingestion (Tamaki and Sonoki 1999). The quantities of these compounds arising from heat-treated garlic were smaller than those from raw garlic. These compounds had the tendency of decreasing with the passage of time. In contrast, almost no high-molecular sulfur compounds (HMSC) were detected in both raw- and heat-treated garlic. Raw garlic exhibited higher values of volatile compounds, and the higher the values, the stronger the garlic flavour or malodour.

Adverse Garlic/Drug Interaction

Garlic supplements can impede HIV medication (Anonymous 2002; Berginc and Kristl 2013) and may affect intake of other drugs (James 2001; Berginc and Kristl 2013). In a study of healthy volunteers, garlic supplementation to saquinavir treatment was found to decrease the content of saquinavir in the plasma by about 50 % (Piscitelli et al. 2002). The authors reiterated that patients should use caution when combining garlic supplements with saquinavir as a sole protease inhibitor for AIDS therapy. The blood-thinning effects of warfarin were greatly enhanced in individuals taking garlic and could amplify the risk of bleeding problems (Sunter 1991). Two herbal supplements in particular, *ginkgo biloba* and garlic, had demonstrated effects on warfarin (Evans 2000).

Adverse Oxidising Activity in Canines

Five compounds, namely, *bis*-2-propenyl trisulfide (**1**), *bis*-2-propenyl tetrasulfide (**2**), *bis*-2-propenyl pentasulfide (**3**), *bis*-2-propenyl thiosulfonate (**4**) and *trans*-sulfuric acid allyl ester 3-allylsulfanyl-allyl ester (**5**), oxidising canine erythrocytes were isolated from an aqueous ethanol garlic extract (Hu et al. 2002). A mixture of compounds **1–3** and compounds **4** and **5** induced methaemoglobin formation in canine erythrocyte suspension in-vitro resulting in the oxidation of canine erythrocytes. The constituents of garlic had the potential to oxidise erythrocytes and haemoglobin, suggesting that foods containing quantities of garlic should be avoided for feeding dogs. Also *trans*-sulfurous acid allyl ester 3-allylsulfanyl-allyl-ester, 2-propene-1-sulfinothioic acid-S-methyl ester and 2-propene-1-sulfinothioic acid-S-(*E*)-1-propenyl ester isolated from aqueous ethanol garlic

extract induced methaemoglobin formation in a canine erythrocyte suspension in-vitro resulting in the oxidation of canine erythrocytes (Yang et al. 2003).

Toxicity Studies

Animal studies found that swelling of the liver, hypertrophy of the spleen and adrenal glands and decrease of erythrocytes with various morphological changes were clearly observed in young rats after 3 and 8 days on the group with high-dosed raw garlic juice, but almost these changes were not observed at any time on extracted-aged garlic juice administration (Nakagawa et al. 1980). The growth of rats in the raw garlic juice-administered group was retarded. In oral chronic toxicity in Wistar rats, no toxic symptoms due to garlic extract even at a dose level of 2,000 mg/kg for five times a week during 6 months were found (Sumiyoshi et al. 1984). High dose of garlic extract did not inhibit the body weight gain, while the food consumption decreased slightly for the nutritional effects of it in both male and female rats. There were no significant differences in urinary, haematological and serological examinations compared to each groups. In the histopathological findings, no toxic signs were observed on any of the tissues and organs examined. In the acute toxicity test of garlic, the LD_{50} values of garlic extract by per os (PO), intraperitoneal (IP) or subcutaneous (SC) administration was estimated over 30 mL/kg, respectively, in male and female of Wistar rats and ddY mice (Nakagawa et al. 1984). In 30 mL/ kg of I.P. group, five of ten in male rats and one of ten in female rats were died within a day after administration; however, no specific signs due to garlic extract were observed in survivals for 7 days. Studies showed that garlic extract, 300 and 600 mg/kg/24 hour for 21 days, caused toxic effects affecting weight growth, biological parameters and histologic structures in female and male rats (Fehri et al. 1991).

Significant rise in urea and D-aspartate aminotransferase and inhibition of alkaline phosphatase in serum were observed in rats fed with garlic extract (2 mL/100 g body weight, intragastrically) for 10 days (Joseph et al. 1989). The liver showed histological changes. Garlic oil feeding (10 mg/100 g body wt, intragastrically) after 24 hour fasting was found lethal. The cause of death appeared to be acute pulmonary oedema. However, similar feeding of garlic oil was well tolerated by rats in the fed state. Also, 24 hour-fasted rats could tolerate this dose of garlic oil, provided they were previously adapted to garlic oil feeding. A case of spontaneous spinal epidural haematoma causing paraplegia secondary to a qualitative platelet disorder from excessive garlic ingestion was reported by Rose et al. (1990). The case also demonstrated satisfactory recovery from thoracic spinal epidural haematoma in a nonagenarian. Administration of low doses of garlic (50 mg/kg) to rats either orally or intraperitoneally had little effect on the lung and liver tissues as compared to control animals (Alnaqeeb et al. 1996). In contrast, administration of high doses of garlic (500 mg/kg) resulted in profound changes in the lung and liver tissues of rats. Intraperitoneal administration of the high dose of garlic was more damaging to the lung and liver tissue of rats than oral administration. This was also confirmed by studies of Banerjee et al. (2001) and Rana et al. (2006). Administration of fresh garlic homogenates at low doses 250 mg/kg/day to rats significantly reduced thiobarbituric acid reactive substances (TBARS) and glutathione peroxidase. Both 500 and 1,000 mg/kg/day doses significantly reduced endogenous antioxidants (catalase and SOD) without altering TBARS. A 1,000 mg/kg/day dose of garlic caused marked histopathological and ultrastructural changes in both the liver and kidneys. The results indicated that garlic in low doses had the potential to enhance the endogenous antioxidant status, although at higher doses a reversal of these effects was observed. Rana et al. (2006) found that garlic at high dose (5 g/kg body weight/day) had the potential ability to induce liver damage, and low doses (0.1 or 0.25 g/kg body weight/day) were safe doses.

The low dose of garlic oil suppressed endotoxin-induced inducible nitric oxide synthase (iNOS) activity, ulceration and apoptosis in the intestinal mucosa of Wistar rats (Chiang et al. 2006). The high dose of garlic oil significantly

lowered the peripheral level of nitrate/nitrite and endotoxin-induced iNOS activity in the rat intestinal mucosa but worsened intestinal mucosal damage accompanied by elevated peripheral proinflammatory cytokines. Diallyl trisulfide but not diallyl disulfide showed similar toxic effect as that of high-dose garlic oil. The results suggested the preventive effect and possible toxicity of garlic oil and its organosulfur compounds in endotoxin-induced systemic inflammation and intestinal damage. Studies by Hamlaoui-Gasmi et al. (2012) showed that a high garlic dose induced liver toxicity and a pro-oxidative status characterised by increased malondialdehyde and decreased antioxidant enzyme activities as catalase, peroxidase and superoxide dismutase. Also, garlic increased intracellular H_2O_2 but decreased free iron and Ca^{2+}. Grape seed and skin extract alone or in co-treatment with garlic had the reverse effect and counteracted almost all garlic-induced deleterious impacts to near control levels. Studies in young (6-week-old) male C57BL/6 mice showed that diallyl disulfide (DADS) may have adverse effects on hippocampal neurogenesis and neurocognitive functions by modulating ERK (extracellular signal-regulated kinase) and BDNF (brain-derived neurotrophic factor)–CREB (cAMP response element-binding protein) signalling (Ji et al. 2013). The results suggested caution in consuming large amounts of garlic products particularly during the period of neural growth.

In a randomised, double blind, placebo-controlled, parallel group clinical trial of 58 newly diagnosed, smear-positive pulmonary tuberculosis patients (31 given garlic tablets, 27 placebo tablets), no significant difference was found between the two groups regarding age, sex, nationality, smoking, underlying diseases and opium usage. During 8 weeks of anti-TB (antituberculosis) treatment, 8 (13.0 %) patients developed drug-induced hepatotoxicity (DIH). Fifty percent of the patients who developed DIH were in the garlic group. Results indicated no significant difference between groups in developing DIH.

Studies indicated that garlic could affect beneficial probiotic *Bifidobacterium* species in a manner similar to that exhibited in pathogens (Booyens et al. 2014). The results highlight that caution should be taken especially when using raw garlic and probiotic bifidobacteria simultaneously as the viability of these bacteria could be reduced by allicin released upon the crushing of garlic cloves, thereby limiting the health benefits that the consumer anticipates to gain from probiotics.

Garlic Chemical Burn and Allergy

Garlic had been reported to be safe in low doses, but it could lacerate the stomach if taken in excessive amounts (Ayaz and Alpsoy 2007). A case of contact dermatitis to garlic was reported by Bleumink et al. (1972). Patch tests with a piece of garlic bulb and extracts of garlic were positive. The active substance proved to be readily soluble in water, alcohol and acetone. The allergenic material was found to be of low molecular weight, heat labile and present in the outer parts of the bulb. Garlic was found to be a type 4 allergen (Cronin 1987). Dilutions of garlic and of onion 50 % in *Arachis* oil were not irritants and seemed effective patch test materials for hand eczema of caterers.

Lybarger et al. (1982) reported that repeated exposure to garlic dust induced severe asthma in an atopic patient. Subsequently, the patient also developed marked adverse responses after ingestion of garlic. Immunological investigations carried out in an asymptomatic period revealed significant skin reactivity and bronchospasm after challenge with both garlic dust and extract. The results of a controlled oral challenge test to garlic dust were also positive. The patient's serum contained unusually high quantities of garlic-specific IgE. Inhalation of garlic dust can cause severe asthma (Armentia and Vega 1997).

Eight Chinese patients developed contact dermatitis after rubbing the cut end of a fresh garlic bulb onto the skin to treat fungal and other infections at the groin, neck, lower limb, hand or face (Lee and Lam 1991). Repeated open application tests with fresh garlic were all positive, and patch tests with garlic extract were all negative. The results confirmed that the contact dermatitis was due to irritation. The patients were treated successfully with topical fluorinated steroid.

Añibarro et al. (1997) reported on 12 patients (all of them garlic workers) with occupational asthma induced by garlic dust. Garlic sensitisation was demonstrated by bronchial challenge test in seven patients (group 1) and ruled out in the remaining five. One nursing mother received severe burns to the breast from prolonged (2 days) application of a poultice of raw, crushed garlic to treat a self-diagnosed *Candida* infection (Roberge et al. 1997). Friedman et al. (2006) reported three patients with self-inflicted garlic burns. Garlic application could result in local inflammation, but, if applied under a pressure bandage or poor wound care or a secondary infection, it could cause a severe dermal reaction and a deep chemical burn.

Raw garlic, when cut and placed on the tongue or lips, elicits painful burning and prickling sensations through unknown mechanisms (Macpherson et al. 2005). They showed that raw but not baked garlic activated TRPA1 and TRPV1, two temperature-activated ion channels that belong to the transient receptor potential (TRP) family. They further showed that allicin, an unstable component of fresh garlic, was the chemical responsible for TRPA1 and TRPV1 activation and was therefore likely to cause garlic's pungency.

Bagga et al. (2008) reported a case of chemical burn of oral mucosa caused by crushed garlic. To relieve toothache, the patient placed crushed garlic cloves in the buccal vestibule overnight and developed garlic burn injury manifesting as slough and ulceration in that region. Allergic contact cheilitis to garlic characterised by inflammation of the lips was reported by Ekeowa-Anderson et al. (2007).

Another case of garlic chemical burn was reported in a 23-year-old woman who developed chemical burn after applying crushed garlic on a wart on her right cheek and placing a tape over it (Filobbos et al. 2012). Garlic was found to cause severe chemical burn in a 41-year-old man with chronic pruritus on the left shin following garlic applied under occlusion (Xu et al. 2014a).

Garlic-sensitive patients showed positive tests to garlic compounds diallyl disulfide, allylpropyldisulfide, allyl mercaptan and allicin (Papageorgiou et al. 1983). Guinea pigs sensitised to garlic extracts cross-reacted to diallyl disulfide and reacted to allicin, an oxidised derivative of diallyl disulfide present in garlic. Pérez-Pimiento et al. (1999) reported an IgE-mediated anaphylactic reaction to young garlic in a patient sensitised to pollen and dried fruit. Prick-prick tests with young garlic and garlic were positive. Alliin lyase was found to be a major garlic allergen in a garlic-allergic group of patients in Taiwan (Kao et al. 2004). Skin tests showed that the purified protein elicited IgE-mediated hypersensitive responses in patients with garlic allergy. Skin tests showed that the purified protein elicited IgE-mediated hypersensitive responses in patients with garlic allergy. Garlic alliin lyase showed strong cross-reactivity with alliin lyases from other *Allium* species, namely, leek, shallot and onion. Ma and Yin (2012) reported a case of anaphylaxis induced by ingestion of raw rather than cooked garlic. IgE banding proteins could only be detected in raw garlic extract but not in cooked garlic as the allergens were heat labile.

In February 1989, three cases of botulism occurred in persons who consumed garlic bread made from a garlic-in-oil product and were reported by Morse et al. (1990). Testing of leftover garlic-in-oil showed it to have a pH of 5.7 and to contain high concentrations of *Clostridium botulinum* organism and toxin. This was the second episode of botulism associated with a low acid garlic-in-oil product which needs constant refrigeration. Gimenez et al. (1988) reported that garlic was not effective in reducing botulinum toxin production by *C. botulinum* type A. Ismaiel and Pierson (1990) reported that garlic oil (100 ppm) inhibited germination of *Clostridium botulinum* A, B and E in broth media but had no significant effect on outgrowth and toxin production.

Unpleasant taste (100 %), halitosis (90 %) and nausea (30 %) after using garlic mouthwash for 5 weeks were reported by 30 subjects after the end of the study (Groppo et al. 2007).

Traditional Medicinal Uses

Garlic is said to be a diaphoretic, diuretic, expectorant, febrifuge, stimulant, stomachic, tonic, anthelmintic,

antiasthmatic, anticholesterolaemic, antiseptic, antispasmodic and cholagogue (Grieve 1971; Lust 1974; Launert 1981). Onion and garlic rich in several phytonutrients are recognised as important elements of the Mediterranean diet, but are also used in the treatment and prevention of a number of diseases, including cancer, coronary heart disease, obesity, hypercholesterolaemia, diabetes type 2, hypertension, cataract, microbial infections and disturbances of the gastrointestinal tract (e.g. colic pain, flatulent colic and dyspepsia), because of their hypocholesterolaemic, hypolipidaemic, antihypertensive, antidiabetic, antibiotic, antithrombotic and antihyperhomocysteinaemia effects and to possess many other biological activities including antimicrobial, antioxidant, anticarcinogenic, antimutagenic, antiasthmatic, immunomodulatory and prebiotic activities (Kendler 1987; Augusti 1996; Bianchini and Vainio 2001; Lanzotti 2006; Corzo-Martínez et al. 2007). Fenugreek, garlic and onion are recommended in Persian folklore medicine as beneficial in the treatment of diabetes (Jelodar et al. 2005). Today, in many parts of the world, garlic is being used both as prophylaxis and for the cure of variety of diseases including acute and chronic infections like gastritis, dysentery, typhoid fever, cholera, tuberculosis, pneumonia, diabetes mellitus, heart disease and hypertension (Khataibeh et al. 2006). In the Errachidia province in southeastern Morocco, garlic and onion are among several plants used most frequently to treat hypertension (Tahraoui et al. 2007). Traditionally, garlic has been known to boost the immune system; aged garlic has more potent immunomodulatory effects than raw garlic (Chandrashekar and Venkatesh 2009). Garlic and onion have been used as medicinal agents for thousands of years (Ali et al. 2000b). Both garlic and onion had been shown to have applications as antimicrobial, antithrombotic, antitumour, hypolipidaemic, antiarthritic and hypoglycaemic agents. *Allium sativum* (garlic)-derived preparations are used alone or with amphotericin B in Asia to treat human systemic fungal infections and cryptococcal meningitis (Davis et al. 1994). Therapeutic properties of garlic have been recognised in the processing of garlic capsules, tablets and other formulations related to human health (Augusti 1996). Aged black garlic is a type of fermented garlic (*Allium sativum*) which has been used in Oriental countries for a long time because of the various biological properties of garlic derivatives (Lee et al. 2011).

According to Burkill (1966) in Peninsular Malaysia, garlic was administered internally for flatulence. It was used in a tonic preparation with other herbs in *ubat jamu* after childbirth. Garlic was prescribed chiefly in herbal mixtures for treating intestinal ailments of various kinds, with *Tinospora* as vermifuge; with galangal and pepper for diarrhoea; with *Aloe* and pepper in a purge; with turmeric, *Nigella* seeds, cumin and coriander and *Massoia* for vomiting; with *Citrus hystrix* peels, *Nigella* seeds and cloves for stomach pains; and with *Cnesti*, *Artocarpus* and *Nigella* for chronic colonic obstruction. Garlic was also prescribed for improving appetite and for correcting effects of gluttony. Garlic was given with *Carum copticum* for coughs and was used as an ingredient in prescriptions for headaches, gouty pains, liver congestions, asthma and various feminine complaints.

According to Grieve (1971) garlic has been used as an antiseptic during the past two world wars. Garlic has been employed as a specific for leprosy and also smallpox. Garlic was used as an antiseptic in ointment and lotions to disperse hard swelling and in poultices for scrofulous sores. Garlic was also used to prevent anthrax in cattle. Syrup of garlic was found invaluable as medicine for asthma, hoarseness, cough, breathing difficulty and other pulmonary disorders. Garlic was also useful in chronic bronchitis, tuberculosis and dropsy. Garlic was crushed and mixed with lard to relieve whooping cough by rubbing on the chest and back. An infusion of bruised garlic bulb before and after every meal gave good effect in epilepsy. Garlic cloves pounded with honey taken 2–3 consecutive nights were good for rheumatism. Bruised garlic in boiled milk was taken as vermifuge. Garlic was also used as a digestion aid.

According to Stuart (2014), in the Philippines, garlic bulbs were used for hypertension, as a diuretic and eaten fresh or burned for coughs in children. Crushed garlic was rubbed on affected areas in arthritis, rheumatism and toothaches.

Crushed cloves were applied to both temples as poultice for headache. Garlic is rubbed over ringworm with a relieving effect. In Mexico, fresh bulb is eaten as prevention for tuberculosis. In India, garlic juice diluted in water is applied externally to prevent hair from turning grey. In the Antilles, garlic juice is used as vermifuge. Juice of garlic bulb with common salt is applied to bruises and sprains, also used for neuralgia and earache. Crushed garlic juice or cut clove crosswise was rubbed directly to areas of insect bites of scorpions, centipedes and the like to mitigate the pain (Chiej 1984; Stuart 2014).

According to Lu (2005) in traditional Chinese Medicine, garlic is good for cold abdominal pain, oedema, diarrhoea, dysentery and whooping cough. He reported that there had been fewer cases of pulmonary tuberculosis in Shandong province where people consumed more garlic than other provinces. As a result of these findings, garlic had been made into tablets and used with good results. Also Chinese people consumed large quantities of garlic in cases of malnutrition or oedema.

Other Uses

Garlic plant and bulb contain phytochemicals that exhibit pesticidal activities against plant pests (insects and nematodes) and diseases (bacterial and fungal). The growing plant is said to repel insects, rabbits and moles (Riotte 1978). The juice from the bulb is used as an insect repellent (Chiej 1984). Several tablespoons of chopped garlic and grated soap infused in boiling water, when cooled, are used as an insecticide (Allardice 1993). An extract of the plant is also used as a fungicide in blight and mould or fungal diseases of tomatoes and potatoes (Allardice 1993). A few cloves of garlic spread among stored fruit will delay fruit from rotting (Chiej 1984).

Garlic oil exhibited insecticidal activity against the eggs, larvae and adults of *Tribolium castaneum* and adults of *Sitophilus zeamais* (Ho et al. 1996). The eggs were the most susceptible stage, followed by adults, 10-day-old larvae and older larvae. *T. castaneum* adults were more susceptible to garlic oil than *S. zeamais* adults, with KD_{50} values of 1.32 mg/cm^2 and 7.65 mg/cm^2, respectively. When rice and wheat were treated with garlic oil, eggs that were laid in the media failed to produce F1 progeny at concentrations of >2,000 ppm in rice for *T. castaneum* and 5,000 ppm in wheat for *S. zeamais*. Methyl allyl disulfide and diallyl trisulfide, two major garlic compounds, exhibited contact toxicant, fumigant and feeding deterrent activity against stored product pests *Sitophilus zeamais* and *Tribolium castaneum* (Huang et al. 2000). Purified garlic leaf lectin (ASAL), a 12 kDa dimeric mannose-binding protein, was found to have detrimental effect on the growth and survival of two important homopteran insect pests, *Lypaphis erysimi*, commonly known as aphids, and *Dysdercus cingulatus* (red cotton bug) (Bandyopadhyay et al. 2001). Horseradish, anise and garlic oils showed the most potent insecticidal activities against larvae of *Lycoriella ingénue* among the plant essential oils (Park et al. 2006). At 1.25 µL/L, horseradish, anise and garlic oils caused 100,93.3 and 13.3 % mortality. Garlic bulb extracts exhibited repellancy and mortality effects against *Tetranychus urticae* (Hincapie et al. 2008). Extracts were obtained using as solvents CO2 in supercritical conditions and had the lowest mean lethal concentration (LC_{50}), and the petroleum ether extract was the most repellent.

Studies by Yang et al. (2010) suggested that garlic essential oil combined with diatomaceous earth had a strong additive effect against adult rice weevils, *Sitophilus oryzae*, and red flour beetles, *Tribolium castaneum*. The activity of the combination treatment lasted longer than that of essential oil alone, and the survival of eggs or larvae to adult stage was significantly inhibited in the combined treatments against both species, compared with the use of essential oil alone. Diallyl trisulfide was found to be more potent than methyl allyl disulfide. The essential oil of *A. sativum* possessed contact toxicity against overwintering adults of *Cacopsylla chinensis* with an LC_{50} value of 1.42 µg per adult (Zhao et al. 2013). The two main constituent compounds, diallyl trisulfide and diallyl disulfide, exhibited strong acute toxicity against the

overwintering *C. chinensis*, with LC_{50} values of 0.64 and 11.04 µg per adult, respectively. Synthetic fusion-protein containing domains of Bt Cry1Ac and *Allium sativum* lectin (ASAL) conferred enhanced (8-fold and 30-fold) insecticidal activity against major lepidopteran pests, *Pectinophora gossypiella* and *Helicoverpa armigera* (Tajne et al. 2014). Afolabi-Balogun et al. (2012) isolated and characterised a mannose-binding insecticidal lectin gene BLEC1from garlic. The cloning and characterisation of BLEC1 would pave the way for its potential use in plant genetic engineering in the development of insect resistance plant. Studies showed that garlic essential oil, diallyl disulfide and diallyl trisulfide, had significant fumigant activity against the angoumois grain moth, *Sitotroga cerealella*, with 50 % lethal concentration values at 1.33, 0.99 and 1.02 µL/L air space, respectively; meanwhile, the three materials possessed high behavioural deterrent activities against adults in the Y-tube olfactometer (Yang et al. 2012). When applied to rice grains, these materials reduced adult longevity and inhibited oviposition, with ovipositional inhibition above 70 % at a concentration of 1.5 µL/25 g in either no-choice or two-choice tests. Garlic extracts exhibited acaricidal activity against the two-spotted spider mite, *Tetranychus urticae* (Attia et al. 2012). Female mortality increased with garlic concentration, with LD_{50} and LD_{90} values of 7.49 and 13.5 mg/L, respectively. Reduced fecundity was observed at concentrations of 0.36 and 0.74 mg/L. Aqueous and methanol garlic extracts showed the highest insecticidal activity (mortality rate of 81 % and 64 %, respectively) against the larvae of *Spodoptera litura* (*S. litura*) at a concentration of 1,000 ppm (Meriga et al. 2012).

Antimicrobial activity in-vitro of garlic allicin was shown against the plant pathogenic bacteria *Agrobacterium tumefaciens*, *Erwinia carotovora*, *Pseudomonas syringae* pv. *maculicola*, *Pseudomonas syringae* pv. *phaseolicola*, *Pseudomonas syringae* pv. *tomato*, *Xanthomonas campestris* pv. *campestris*, the fungi *Alternaria brassisicola*, *Botrytis cinerea*, *Plectosphaerella cucumerina*, *Magnaporthe grisea* and the oomycete *Phytophthora infestans* (Curtis et al. 2004). Disease reduction in plants by allicin was shown for *Magnaporthe grisea*-infected rice, *Hyaloperonospora parasitica*-infected *Arabidopsis thaliana* and *Phytophthora infestans-infected* potato tubers. Significantly, the active principle was effective in reducing *P. infestans* spore germination in-vitro and disease in blighted tubers via the vapour phase (fumigation) as well as by direct application at the inoculation site. Horseradish ethanol extracts exhibited fungistatic activity against *Sclerotium rolfsii*, *Fusarium oxysporum* and *Fusarium culmorum*, while garlic extracts at the same concentration provided a good fungicidal activity against *Botrytis cinerea* and *S. rolfsii* (Tedeschi et al. 2011). Antifungal N-feruloyl amides *N*-feruloyltyrosine and *N*-feruloyltyramine, isolated from *A. sativum* roots, showed antifungal activity towards *Fusarium culmorum* (Fattorusso et al. 1999).

Furostanol saponins isolated from garlic bulbs exhibited antimicrobial activity towards two fungal species, the airborne pathogen *Botrytis cinerea* and the antagonistic fungus *Trichoderma harzianum* (Lanzotti et al. 2012). Three furostanol saponins ceposide A–ceposide C exhibited antifungal activity (Lanzotti 2012). Saponin ceposide B showed a significant growth inhibition of all fungi *Botrytis cinerea*, *Trichoderma atroviride*, *Trichoderma harzianum*, *Mucor* sp., *Alternaria alternata* and *Phomopsis* sp. with the exception of *Fusarium oxysporum* f. sp. *lycopersici*, *Sclerotium cepivorum* and *Rhizoctonia solani*. Ceposide B was the only one capable of inhibiting the growth of *Aspergillus niger*. Ceposides A and C were effective in reducing the growth of all fungi with the exception of *A. niger*, *S. cepivorum* and *Fusarium oxysporum* f. sp. *lycopersici*. Seven compounds isolated from garlic showed significant antifungal activity against *Trichoderma harzianum*, and only five compounds were effective against *Botrytis cinerea* (Lanzotti 2012; Lanzotti et al. 2012). In general, the isolated compounds showed the following rank of antifungal activity: spirostanol saponin 34> spirostanol saponin 33 = voghieroside C > voghieroside B = the two eugenol glycosides > voghieroside A. The most promising compound appeared to be voghieroside C that

showed a significant growth inhibition of both fungi. The root exudates from 10- to 60-day-old plants of garlic inhibited the germination of 3 crops (lettuce, rape and radish) and mycelial growth of 6 pathogens (*Pythium helicoide*, *P. irregular*, *P. ultimum*, *P. violae*, *P. heterothal* and *P. sylvati*) (Yuan et al. 2012). The inhibitory effects of root exudates were highest from the 30- and 40-day-old garlic plants. However, the hypocotyl growth of test crops was stimulated.

Recent studies indicated the polysulfides present in garlic to be with activity against free living nematodes that damaged carrot and parsnip crops and root-knot nematodes that damaged carrot and tomato crops (Anwar et al. 2009). Allicin, from garlic, at 25 ppm for 5 minutes as a root-dip treatment was effective against the nematode, *Meloidogyne incognita* (Gupta and Sharma 1993). Allicin reduced egg hatching and killed nematode juveniles. An aqueous garlic extract, salicylaldehyde; a nonylphenol ethoxylate surfactant; and a formulation containing these constituents exhibited in-vitro nematicidal effects against the potato cyst nematode, *Globodera pallida* (Danquah et al. 2011). The formulation caused 100 % mortality at 75.0 µL/L with an LC_{50} of 43.6 µL/L after 24 hours exposure. Salicylaldehyde was the most toxic constituent of the formulation with an LC50 of 6.5 µL/L after 24 hours, while the garlic extract achieved 50 % J2 mortality at 983.0 µL/L µL/L, demonstrating that the formulation and salicylaldehyde are more toxic to *G. pallida* in-vitro than oxamyl but less toxic when compared with aldicarb.

N-terminal fusion of the *Allium sativum* leaf agglutinin (ASAL) with SUMO (small ubiquitin-related modifier) peptide, SUMO-ASAL, may be a preferred candidate insecticidal protein for the development of transgenic plants Upadhyay et al. (2010).

A formulation consisting of 2 mL of aqueous garlic extract and 25 ppm Zn^{2+} afforded 70 % inhibition efficiency in corrosion inhibition of carbon steel immersed in well water (Rajam et al. 2013). Polarisation study revealed that this formulation controlled the anodic reaction predominantly. FTIR spectra revealed that the protective film consisted of Fe^{2+}–allicin complex and Zn(OH). An excellent glue made from garlic juice when spread on glass, it enables a person to cut clean holes in the glass (Chiej 1984). Garlic juice is also used as a glue in mending glass and china (Uphof 1968).

Garlic is also steeped in mysticism and mythology. In Europe, garlic is used for protection or white magic; in central Europe, garlic is regarded as a powerful deterrent against demons, werewolves and vampires (Mcnally 1994). To ward off vampires garlic could be worn, hung in windows or rubbed on chimneys and keyholes. In Buddhism, in the *Shurangama Sutra* (Mahayana school), Buddha explained how the 'Five Pungent Spices', including garlic and onions, were forbidden (Ohlsson 1998). 'If these five are eaten cooked, they increase one's sexual desire; if they are eaten raw, they increase one's anger'. In Taoism, during the Tang dynasty, people attending the altar in the temple, looking on the dead or newly born, eating the five pungent foods (chives, scallions, onions, garlic and ginger) were forbidden (Pregadio 2008). These prohibitions could extend for 7, 14 or 49 days. In connection with the malodour associated with garlic, Islam views eating garlic and subsequently going to the mosque as inappropriate and should not approach the mosque (Izutsu 1983). The prophet Muhammad dislikes the scent of garlic. The followers of the Krishna sect of Hinduism abstain from eating garlic, onion and mushroom which are deemed to have negative properties (Narayanan 2007).

Comments

Etoh and Simon (2002) summarised the current classification of the *Allium sativum* species based on the morphological, isoenzyme and molecular markers into four informal subspecies: the rather diverse longicuspis group including most garlic from Central Asia; the subtropical group which developed under the climatic conditions of South, Southeast and East Asia; the ophioscorodon group from Central and East Europe; and the Mediterranean sativum group. The sativum

group, probably derived from longicuspis forms in West Asia more than 3,000 years ago, has been grown in the Mediterranean area since ancient times (Etoh and Simon 2002). It has spread from there throughout the world during the last 500 years (Maaß and Klaas 1995). However, the classification of sativum taxon is still ambiguous. Maaß and Klaas (1995) added that the *pekinense* subgroup comes from the east of Asia. Ovesna et al. (2011) found a correlation between the genetic basis of garlic clones as identified by AFLP and cysteine sulfoxide content across 135 genotypes. 286 informative AFLP fragments grouped 135 accessions in eight clusters, and two clusters contained only *A. sativum* L. var. *ophioscorodon* clones; four clusters grouped together both non-bolting and semi-bolting clones, whereas the remaining two contained only non-bolting types. These AFLP markers efficiently differentiated var. *ophioscorodon* from var. *sativum* clones.

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Arracacia xanthorrhiza

Scientific Name

***Arracacia xanthorrhiza* Bancroft**

Synonyms

Arracacha esculenta DC., *Arracacia andina* Britton, *Arracacia esculenta* DC., *Arracacia xanthorrhiza* var. *andina* (Britton) S. Knudsen, Sørensen and Hermann, *Bancroftia decipiens* R.K. Porter, *Bancroftia xanthorrhiza* Billb., *Conium arracacia* Hook.

Family

Apiaceae

Common/English Names

Arracacha (common), Peruvian Carrot, Peruvian Parsnip, White Carrot

Vernacular Names

Aymara: Lakachu, Lecachu

Bolivia: Arracacha (Quechua, Spanish), Lacache (Aymará), Racacham (Qeuchua)

Brazil: Batata–Apio, Batata-Baroa, Batata-Cenoura, Batata-Fiusa, Batata-Jujuba, Batata-Salsa, Batata-Suiça, Batata-Tupinambá, Cenoura Amarel, Mandioquinha-Sals, Pastinaca (Portuguese); Batata-Tupinambá (Tupi)

Chile: Lacache (Aymará)

Columbia: Arocueche (Muzo), Arracacha (Quechua, Spanish), Guaud, Huahué (Paez-Coconuco), Pacucarrá (Chocó Indians), Yengó (Kamsá), Zanahoria (Spanish), Sacarracach

Cuba: Afió, Arracacha

Ecuador: Arracacha (Quechua, Spanish), Zanahoria, Zanahoria Blanca (Spanish)

French: Arracacha, Panème, Pomme De Terre-Céleri

Latin America: Arrecate, Arecate (Spanish)

Peru: Arracacha (Quechua, Spanish), Zanahoria Blanca, Zanahoria Del Pais, Zanahoria Morada (Spanish), Huisampilla, Oqqe, Racacha, Ricacha, Virraca (Quechua)

Puerto Rico: Apio

Spanish: Arracacha, Racacha, Zanahoria Blanca, Apio Criollo, Sonarca

Venezuela: Aricachi (Ayoman), Apio, Apio Criollo (Spanish), Kiu-Tits (Timote), Arrecate, Arecate

Origin/Distribution

Although the genus *Arracacia* is particularly diverse in Mexico, the wild species most closely resembling arracacha are known from Peru and Ecuador (Hermann 1997). Today, arracacha is

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Plate 1 Tuberous arracacha root

produced mainly in four countries – Brazil, Colombia, Ecuador and Venezuela.

Agroecology

Arracacha production areas in the Andes range over 32° of latitude from 10°N (Mérida, Venezuela) to 22°S (southern Bolivia), with marketed production coming mostly from north of the equator (Hermann 1997). It adapts to a wide range of mesothermic and tropical frost-free, montane environments as well as day length regimes.

The plant grows west of the Andes at altitudes varying from 600 to 3,600 m, but optimally between 1,800 and 2,500 m elevation. In Columbia, it is mainly grown in elevations of 1,800–2,500 m, Brazil 1,000–2,000 m, Peru 1,200–3,200 m, Ecuador 1,500–300 m, Bolivia 1,000–3,500 m and Venezuela 1,200–3,200 m. The plant flourishes in areas with temperatures of 14–21 °C and mean annual rainfall of 1,000–1,200 mm, although it will grow in areas with 600 mm rainfall. Arracacha is intolerant of frost and abhors temperatures above 25 °C. It thrives in deep, well-drained, fertile sandy soils rich in organic matter and with soil pH 5–6. It performs well in volcanic soils.

Arracacha is frequently intercropped with maize, beans and coffee or rotated with banana and plantains.

Edible Plant Parts and Uses

Arracacha starchy root (Plate 1) is popularly eaten as a food item in South America and also in some Central American countries (Hodge 1954; National Research Council 1975; Popenoe et al. 1989; Hermann 1997; Noguera and de Delahaye 2000; Garcia et al. 2007). The roots are eaten boiled or as an ingredient in soups and stews, side dishes, in dumplings, gnocchi (a kind of pasta), pastries, as purees, roasted and fried in slices or strips, biscuits and coarse flour.

The roots are used in stews comprised of meat (beef, chicken or pork) and vegetables (potatoes, yucca, peas, lima beans, plantains, oca, ulucuo, mashua, chopped onion, tomato) and cheese. The stews are called *cocido* (in Columbia, Venezuela), *sancocho* (in Columbia), *chupe* (In Peru) and *locro* (in Peru, Ecuador). Variations of this dish include *viudo de pescado* from the Magdalena valley (Tolima, Colombia), in which fish replaces meat and pork, and the *mondongo* from Antioquia, a stew with arracacha, potatoes, sausages and beef tripe as the characteristic ingredients. In modern Brazilian cuisine, a dish called *Soufflé de mandioquinha-salsa* is made from cooked, hot, mashed arracacha with butter and egg yolks. Rio de Janeiro has contrived *batata baroa em calda* (arracacha compote), comprising blanched arracacha pieces being cooked in dissolved sugar. In Minas Gerais, Brazil, descendants of Italian immigrants use arracacha instead of potato in the well-known gnocchi dish. Another common dessert dish is *pastels* in Ecuador or *buñuelos de apio* in Venezuela, this recipe comprised cooked and mashed arracacha roots mixed with butter, eggs and sugar into ball-shaped fritters and fried in oil. In Costa Rica, arracacha is finely chopped and fried with minced meat and onions as a filler in *tortillas de maiz*. Arracacha is also used as a filling for *picadillos*, a traditional Costa Rican dish served on patron saint's day. In Puerto Rico arracacha is used in

alcapurrius, a deep-fried fritter whose dough comprised a mixture of purees from arracacha, glutinous plantain and starchy yautía (*Xanthosoma sagittifolium*) stuffed with meat fillings. Soups and purées having arracacha as their main starchy ingredient are deliciously creamy and light food and provide light nourishment for the sick and infants. In its processing plant in San José de Rio Pardo, São Paulo state, Nestle-Brazil uses arracacha as an ingredient in both wet and dry formulae of instant soups and baby food. Arracacha chips have been available for many years in Quito supermarkets. Arracacha starch is easily digestible and palatable and was widely used for pastry in Colombia during the first half of the nineteenth century. Arracacha starch has been used for making *bocadillos* (cookies) and small spongy cakes called *bizcochuelos*.

The leaves are prepared in the same way as celery in raw or cooked salads, hence the name 'Creole celery' which is given to it in Venezuela. The blanched tender, young stems are used for salad or as cooked greens.

Botany

A stout, caulescent, herbaceous plant, 0.5–1.2 m high, with a short, cylindrical, comose rootstock (10 cm long, 10 cm across) with marked horizontal ring markings. At maturity, from the basal part of the rootstock, two types of roots are produced: long, fine, filamentous roots and a ringlike cluster of slender tuberous and fusiform lateral roots, resembling parsnip, with lustrous off-white skin and white (blanca), yellow (tamarilla) or purple (morada) core. Arising from nodes of the crown (upper part of the rootstock) are a number of cylindrical stems or cormels with close ringlike markings giving rise to aerial branching shoots bearing leaves and inflorescences. Leaves resemble parsley leaves and have 8–45 cm long petioles with weakly developed basal sheath. Leaves are broadly ovate, 1–3 cm long and broad, biternate or bipinnate, the leaflets ovate–lanceolate to ovate, 4–12 cm long, 1.5–6.5 cm wide, acuminate, mucronate–serrate and coarsely incised or lobed, squamulose or scaberulous. The inflorescences are terminal, composite umbels with involucres bractlets and bearing small, actinomorphic and epigynous, flowers on 2–4 mm pedicels. Male (staminate) and bisexual flowers are similar except that the male flowers lacks functional female organs. Bisexual flowers have five purplish-maroon oval petals, five stamens and a bicarpellate inferior ovary, each carpel with one ovule. The styles (three or four) emerge from an epigynous disc which functions as a nectary. The styles are basally enlarged to form the more or less conical stylopodium. Fruit oblong one-seeded achene, 10 mm long by 2–3 mm across, constricted below apex and has prominent ribs.

Nutritive/Medicinal Properties

Composition of arracacha per 100 g edible portion was reported as energy 103–105 cal, moisture 73–75 %, protein 0.11–0.9 %, fat 0.2–0.36%g, carbohydrates 24.7–28.70 %, fibre 0.75–0.95 %, ash 1.2–1.4 %, K 2.1–2.4 mg, Ca 29.2–34.2 mg, P 45–55 mg, Mg 62.1–64 mg, Fe 8–10 mg, thiamine 0.1 mg, niacin 4.15–4.45 mg, vitamin A 1.75–1.77 mg and ascorbic acid 22–24 mg (ACNF 2009).

Matsuguma et al. (2009) reported the chemical composition of arracacha roots (range of two varieties at two production sites) as moisture 69.9–74.5 %, ash 4.23–4.85 %, protein 4.18–6.11 %, total carbohydrate 77.5–82.2 %, starch 77.5–82.2 %, lipid 0.61–1.39 % and fibre 9.17–10.9 %; arracacha starch as moisture 6.86–10 %, ash 0.05–0.31 %, protein 0.14–0.26 %, total carbohydrate 99–99.4 %, starch 97.6–98.7 %, lipid 0.39–0.42 % and fibre 0 %; and arracacha bagasse as moisture 6.25–7.8 %, ash 1.44–1.83 %, protein 1.83–2.52 %, total carbohydrate 75.3–81.8 %, starch 67.6–69.2 %, lipid 0.3–0.73 % and fibre 14–20.1 %. Carboxyl content of arracacha starches were w/w (wet weight basis) native 0.18–0.21 % and modified 0.29–0.34 %; reducing power mg Cu/g starch were native 23.5–49.4 mg and modified 47.4–73.4 mg; swelling power of starch14.5–21 times at 65 °C, 18,9–26.5 times at 75 °C and 35.4–56.9 times at 85 °C; solubility of

starch 9.6–10.4 % at 65 °C, 16.9–30.1 % at 75 °C and 39.2–82.8 % at 85 °C (Matsuguma et al. 2009). The carboxyl content, the reducing power and the amount of the water liberated from the pastes after freeze-thawing were higher for the oxidised starches, and their pastes were clearer than those of the native starches of the two varieties from the two production areas. All the oxidised samples had lower pasting temperatures (from 57.2 to 61.9 °C) than their respective native counterparts (from 59.1 to 62.5 °C). In the thermal analysis, the temperatures of the pyrolysis were higher for the native than for the modified starches. The native starches in all the solvents had higher tendency to retrogradation (from 40 to 72 RVU) than the modified ones (0.7–21 RVU). For the soups, they suggested that low viscosity starches should be preferred, but for the use as the gelling agent in the pie filling, a high viscosity would be desired for preventing the spilling during the transportation. Native starch was found to have 38.2–47.1 % paste clarity and modified starch 86–96.5 paste clarity. Higher amylose contents produced opaque pastes, and lower contents produced clear, transparent pastes. More opaque pastes like arracacha native starch would be desired for foods like puddings and ready-to-eat desserts. The modified starches, on the other hand, produced the transparent pastes and could be used on the pie fillings, for example.

Arracacha starch granules were irregular-shaped with granular sizes between 7 and 23 μm, amylose content of 4 %, amylopectin with average chain length of 22.6 and β-amylolysis limit of 56.6 %, B-type X-ray diffraction pattern, gelatinisation enthalpy of 17.6 J/g and peak temperature of the endothermic DSC (differential scanning calorimetry) transition was 60.1 °C (Santacruz et al. 2002). A decrease in pH from 6.5 to 4.0 resulted in a reduction of the elastic modulus for arracacha starch. Storage of arracacha starch gels at 4 °C showed that *A. xanthorriza* formed gels which were stable in elastic modulus and phase angle for 3 days of storage (Santacruz et al. 2003). Storage at freezing temperature (−20 °C) produced higher changes in elastic modulus than refrigeration conditions. Arracacha carrot starch presented round and irregular-shaped granules, low amylose content and B-type X-ray diffraction pattern (Rocha et al. 2011). Amylopectin of this starch contained a large proportion of long degree of polymerisation (DP>37) and short (DP 6–12)-branched chains. Arracacha starch had structural characteristics that differed from those of cassava and potato starches. Annealing affected the semicrystalline structure of this starch, enhancing its crystallinity, mainly due to a better interaction between amylopectin chains. Pérez et al. (1999) reported arracacha starch granules to be spherical or truncated egg-shaped, ranging from 4 to 26 um in diameter. The starch was similar in gross chemical composition and basic physical to cassava starch but differed in pasting properties, with arracacha starch showing lower breakdown and consistency indices. The two starches also showed different water absorption and solubility patterns.

Arracacha flour formulation of 60 % flour was found to contain high levels of protein (10.07 %), carbohydrates (58.3 %), fat (10.07 %) and dietary fibre (8.53 %, resistant starch 2.3–2.38 %) as well as minerals P, Ca, Fe and Mg (García et al. 2007). Stability analysis during 90 days at room temperature showed that the low moisture content (5.75 %) and water activity maintained functional characteristics of high water absorption, solubility and starch swelling power. In-vitro digestibility was high (79.2 %) showing easy digestion as soup. The results suggested arracacha flour to be a good ingredient for soup-type products with high nutritional and energy properties.

Boiling at 99.5 °C for 20 minutes was found to be the best method to cook arracacha root due to a high retention of total phenolics (TP), total carotenoids (TC) and in-vitro antioxidant capacity (AC) in comparison to oven cooking at 200 °C for 45 minutes and microwave cooking at 800 W for 5 minutes (Pedreschi et al. 2011). During boiling, chlorogenic and caffeic acids and derivatives remained relatively stable. The drying temperature was negatively correlated to the residual content of TP and AC for the yellow and cream arracacha roots, but for the cream/purple arracacha variety, blanching preserved the TP and AC. Significant losses in chlorogenic and caffeic acids and derivatives were mainly observed during hot-air drying.

Chemical composition (g/100 g) of arracacha root chips was reported as: moisture 2.87–3.97, fat 17.38–23.91, ash 2.38–2.96, dietary fibre 6.38–8.26, raw protein 2.40–3.27, starch 30.51–40.40, total sugar 4.83–11.53 and reduced sugar 1.65–3.27 (Noguera and de Delahaye 2000). Results of the sensorial evaluation indicated that chips prepared in sunflower oil without blanching have the best overall quality. During storage, significant differences were found for texture. It was concluded that arracacha chips not blanched and fried in sunflower oil exhibited the highest nutritional quality, due to the lower fat content and superior sensorial rating.

Arracacha roots obtained from plants grown without the addition of poultry litter to the soil and bleached after harvest were the ones that best maintained their chemical characteristics, for a period of 5 months of storage at −18 °C (De M Buso et al. 2014). Total titratable acidity, pH, β-1, 3-glucanase activity in roots were neither significantly influenced by the cultivation with poultry litter nor by the treatments for storage. The content of peroxidase was not influenced by the addition of poultry litter, while the content of soluble solids, phenolic compounds and the activity of catalase were not influenced by storage treatments. Carotenoid content was significantly influenced by the addition of poultry litter to the soil and by the postharvest treatment of arracacha roots; it was also influenced by the interaction postharvest treatment/months after harvest and by the interaction poultry litter addition/months after harvest. The highest carotenoid contents were found in roots of plants grown in soil with cover litter and with cover + incorporated litter, followed by a postharvest treatment with bleaching. Buds used for sprouting obtained from plants cultivated in soil with cover litter and treated with chitosan + lemongrass essential oil after harvest maintained their chemical quality for a period of 3 months of storage at 5 °C.

Other Uses

The stump or crown of the roots is used as cattle feed. Fresh stem and leaves are used as animal fodder, while the dried leaves can be used to prepare meal used also as animal feed.

Studies by Medina et al. (2012) reported that arracacha native starch could be acetylated or oxidised to produce biodegradable films for packaging food such as meat and vegetables. Native starch films had lower water solubility and greater stability in acid and alkaline conditions.

Comments

Arracacha is vegetatively propagated using offsets (*colinos*) or shoots produced on the crown of the main rootstock (*cepa*).

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Apium graveolens var. *rapaceum*

Scientific Name

***Apium graveolens* L. var. *rapaceum* (Miller) Gaudin**

Synonyms

Apium graveolens L. (Celeriac Group), *Apium rapaceum* Mill., *Apium graveolens* var.-Gr. *rapaceum* Alef., *Apium graveolens* L. (Rapaceum Group)

Family

Apiaceae

Common/English Names

Celeriac, Celery Root, Knob Celery, Turnip-Root Celery, Turnip-Rooted Celery

Vernacular Names

Afrikaans: Selder
Bulgarian: Tselina
Chinese: Gen Qin Cai
Croatian: Celer
Czech: Celer bulvový
Danish: Knoldselleri
Dutch: Knolselderij
Estonian: Juurseller
Finnish: Mukula Eli Juuriselleri
French: Ache-Douce, Céleri Rave
German: Eppich, Knollensellerie, Sellerie, Wurzel-Sellerie, Wurzelsellerie
Greek: Selinóriza
Hungarian: Zeller
Italian: Sedano Rapa
India: Ka hindi matalab (Hindi)
Japanese: Ne-yō serori
Korean: Selleoli
Latvian: Selerijas
Macedonian: Korenaš
Norwegian: Knollselleri
Polish: Seler Korzeniowy, Selery Korzeniowe
Portuguese: Aipo-rábano
Romanian: Telină
Russian: Kornevoi Sel'derei, Sel'derej Korneplodnyj
Serbian: Celer
Slovaščina: Gomoljna zelena
Slovencina: Zeler voňavý buľvový
Spanish: Apio Nabo, Apio Papa, Apio Rabano, Apirrábano
Swedish: Rotselleri
Turkish: Kerevic
Vietnamese: Củ
Welsh: Seleriac

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Origin/Distribution

Celeriac originated probably in the middle of the sixteenth century in Italy. It is mainly cultivated in Central and Eastern Europe and the Netherlands.

Agroecology

Celeriac is adapted to a temperate climatic regime with monthly mean temperatures of 15–21 °C; the roots is hardy to about −12 °C and can be left in the ground over winter to be harvested as required. The crop thrives best in a moist, rich, friable soil with pH of 5.2–8.3 in open, full sun position. It requires abundant moisture in the growing season; otherwise, the root will be small and tough.

Edible Plant Parts and Uses

Celeriac is a versatile vegetable and can be used both cooked and raw in salads. It is often used as a flavouring in soups, stews and casseroles, but can also be mashed or baked. Mashed celeriac is best when combined with another root vegetable like potatoes to create a smoother mash consistency. One classic dish is celeriac remoulade, where the vegetable is grated or cut into small pieces and served with a mustard mayonnaise. It is also used raw in salads, grated and often tossed with creamy salad dressings. Celeriac combines well with meats such as duck, pork and lamb and herbs such as bay leaves and thyme. Celeriac is also processed for canning, freezing and dehydration. The leaves can also be used as flavouring in soups or eaten raw but have a very strong flavour. The leaves can be dried for flavouring salt. The seed or its essential oil is also used as flavouring agents.

Botany

A deciduous, erect, herbaceous biennial growing to 1 m high by 0.5 m wide with a crown of rosulate celery like pinnate leaves with rhombic leaflets and hollow stalks (Plate 1). The edible portion is the swollen, knobby, rounded to odd shape, 7–12 cm across that is derived from the hypocotyl and part of the tap root and stem beneath the soil surface (Plates 2 and 3). The flesh is creamy white and firm. The flowers are creamy white, 2–3 mm diameter, produced in dense compound umbels. The seeds are broad ovoid to globose, 1.5–2 mm long and wide.

Plate 1 Celeriac with leaves and petioles

Nutritive/Medicinal Properties

Proximate nutrient composition of celeriac per 100 g edible portion (USDA, ARS 2014) was reported as water 88 g, energy kcal 42 (176 kj), protein 1.5 g, total fat 0.3 g, ash 1 g, carbohydrate 9.2 g, total dietary fibre 1.8 g, total sugars 1.6 g, Ca 43 mg, Fe 0.7 mg, Mg 20 mg, P 115 mg, K 300 mg, Na 100 mg, Zn 0.33 mg, Cu 0.07 mg, Mn 0.158 mg, Se 0.7 µg, vitamin C 8 mg, thiamine 0.05 mg, riboflavin 0.06 mg, niacin 0.7 mg, pantothenic acid 0.352 mg, vitamin B 6 0.165 mg,

Plate 2 Harvested celeriac

Plate 3 Odd-shaped, grotesque celeriac

total folate 8 μg, choline 9 mg, vitamin E (α-tocopherol) 0.36 mg, vitamin K (phylloquinone) 41 μg, total saturated fatty acids 0.079 g, 14:0 (myristic acid) 0.002 g, 16:0 (palmitic acid) 0.069 g, 18:0 (stearic acid) 0.006 g, total monounsaturated fatty acids 0.058 g, 16:1 undifferentiated (palmitoleic acid) 0.002 g, 18:1 undifferentiated (oleic acid) 0.065 g, total polyunsaturated fatty acids 0.148 g, 18:2 undifferentiated (linoleic acid) 0.148 g and lutein + zeaxanthin 1 μg. Celeriac had been reported to contain 2.4 mg/100 g apigenin and 0.18 mg/100 g quercetin (Lugasi and Hovari et al. 2000).

Two polyacetylenes – falcarinol and falcarindiol – were identified in Polish celeriac varieties (Jablonska-Rys 2007). The largest amount of falcarinol was found in Makar and Jablkowy celeriac variety, 25.34 and 22.37 mg/100 g dry mass, respectively. Odrzanski and Luna varieties contained the highest amount of falcarindiol 10.13 and 12.55 mg/100 g of dry mass, respectively. Bioactive polyacetylene compounds had been considered to contribute substantially to the beneficial properties of Apiaceae plants including celeriac (Roman et al. 2011). Heterogeneous and tissue-specific occurrence of total and individual polyacetylenes in celeriac roots was shown in Raman maps.

Root and petiole tissues of celery and celeriac accessions were shown to contain linear furanocoumarins (LFCs) when infected with the root fungus *Fusarium oxysporum* f. sp. *apii*. LFC levels were low (<5 ppm) in young celery and celeriac roots 7 weeks postinoculation, but levels as high as 50 ppm were detected in severely rotted celery root and crown tissues of mature 5270R plants (Heath-Pagliuso et al. 1992). The amounts of furocoumarins varied within the batches of celeriac, the sum of the phototoxic furocoumarins being 2.1–4.5 mg/kg (on a fresh weight basis) (Järvenpää et al. 1997). However, the yields obtained by supercritical fluid extraction (SFE) were in agreement with those from Soxhlet extraction. Peroutka et al. (2007) found celeriac to contain only linear furanocoumarins, namely, bergapten (70–3,150 μg/100 g FW), xanthotoxin (40–2,200 μg/g FW), isopimpinellin (140–1,260 μg/100 g FW) and psoralen (10–1,050 μg/100 g FW). Studies by Schulzova et al. (2008) found in all analysed celeriac samples the presence of linear furanocoumarins psoralen, bergapten, xanthotoxin and isopimpinellin; none of angular furanocoumarins (angelicin, sphondin, isobergapten) or linear trioxsalen was detected. The total furanocoumarins content was

relatively low; the average levels of furanocoumarins determined in hardy fresh celeriac roots were 8.8 mg/kg, ranging from 1.7 to 23.5 mg/kg. Content of targeted toxicants was relatively low and obviously does not present health risk for consumers. Schulzová et al. (2012) reported that the average contents of furanocoumarins (psoralen, bergapten, xanthotoxin and isopimpinellin) for all 3 years in Polish celeriac varieties Albin and Kompakt were 2.6 mg/kg and 10.2 mg/kg, respectively. In all crop years, higher levels were found in the variety Kompakt.

Studies by Radziejewska-Kubzdela et al. (2014) found that modified atmosphere packaging of shredded celeriac not subjected to washing or soaking pretreatment made it possible to obtain a product with good sensory and microbiological quality and the highest content of phenolic compounds. The applied pretreatment consisting of washing or soaking of shredded celeriac in water resulted in decreases in 8-methoxypsoralen content by approximately 50 and 70 %, respectively, and phenolic content by 30 % compared with samples that were not subjected to pretreatment. During storage of shredded celeriac, a further significant reduction in phenolic compounds and an approximately 2.5-fold increase in the total content of furanocoumarins were found. The level of furanocoumarins recorded in the tested product posed no health hazard.

Kaiser et al. (2013) identified and quantified 14 phenolic compounds in celeriac (mg/100 g DM): caffeoyl hexose A (6.5 mg), ferulic acid derivative (2.7 mg), caffeoyl hexose B (1.2 mg), quinic acid derivative 10.1 mg, caffeoyl hexose C (tr), caffeic acid derivative 59.4 mg, apiin 180.7 mg, diosmetin-apiosylglucoside/chrysoeriol-apiosylglucoside A (tr), diosmetin-apiosylglucoside/chrysoeriol-apiosylglucoside B (74.7 mg), malonylapiin A (13.4 mg), diosmetin-acetylapiosylglucoside/chrysoeriol-apiosylglucoside A (6 mg), malonylapiin B (21 mg), diosmetin-malonylapiosylglucoside/chrysoeriol-malonylapiosylglucoside (7.7 mg) and total phenolics 386 mg. Individual phenolic compounds were differently affected upon heat treatment. The contents of the main phenolic compound apiin decreased upon heat treatment, whereas the levels of the minor compounds malonylapiin A and B increased. Thermal treatment strongly affected peroxidase and polyphenol oxidase activities of celeriac; enzyme activities decreased with increasing temperature and heating time. Only by extended steam and water blanching at 100 °C, respectively, complete inactivation of peroxidase and polyphenol oxidase was achieved. The obtained celeriac products were characterised by their bright white colour. Consequently, blanching was recommended as the initial operation in the processing of celeriac into novel pasty products.

In carrots, celeriac, scorzoneras and horseradish caffeic acid was found to dominate after hydrolysis (Stöhr and Herrmann 1975). The contents of phenolic acids in the roots were much smaller than in the corresponding leaves. A mannitol–mannose 1-oxidoreductase was isolated from celeriac root tips (Stoop and Pharr 1992). This enzyme catalysed the NAD-dependent oxidation of mannitol to mannose, not mannitol to fructose. The enzyme was strongly inhibited by NADH and sensitive to alterations of NAD/NADH ratio.

Aliphatic C(17)-polyacetylenes of the falcarinol type, which occur in common food plants of the Apiaceae family such as carrot, celeriac, parsnip and parsley, had demonstrated interesting bioactivities including antibacterial, antimycobacterial and antifungal activity as well as anti-inflammatory antiplatelet-aggregatory, neuritogenic and serotonergic effects (Christensen 2011). In addition, the cytotoxicity of falcarinol-type polyacetylenes towards human cancer cells, bioavailability and their potential anticancer effect in-vivo indicated that these compounds may contribute to the health effects of certain vegetables and hence could be important nutraceuticals. Their possible health-promoting effects and recent patents on bioactivity of falcarinol-type polyacetylenes and inventions were also reviewed.

Antioxidant Activity

Upon thermal treatment, the antioxidant capacities (TEAC assay) and the total phenolic contents (TPC) of celeriac remained virtually unchanged

(Kaiser et al. 2013). The TPC in unheated celeriac determined amounted to 123.4 mg GAE/100 g DM. The antioxidant capacities of heated samples determined by the FRAP assay were even higher than those of the unheated control. Steam blanching of celeriac resulted in an increase in the antioxidant capacities, while upon water blanching, the values decreased with increasing blanching time.

Anticancer Activity

Zidorn et al. (2005) tested polyacetylenes isolated from celery against leukaemia, lymphoma and myeloma cell lines. All four polyacetylenes showed at least moderate toxicity to all cell lines, with falcarinol proving to be the most active compound with a pronounced cytotoxicity against acute lymphoblastic leukaemia cell line CEM-C7H2, with an IC_{50} of 3.5 µmol/colorectal cancer cells appeared to be less susceptible than other cell lines in their study. Studies by Kang et al. (2011) found that even if present at low levels in apiaceous vegetables, imperatorin, trioxsalen and isopimpinellin may contribute significantly to cytochrome P450 1A2 (CYP1A2) inhibition and potentially decreased procarcinogen activation. Moreover, the in-vivo effect of isopimpinellin on CYP1A2 may be longer lasting compared to reversible inhibitors.

The polyacetylene falcarinol had been shown to be protective against chemically induced colon cancer development in rats; it was found to have a biphasic effect upon CaCo-2 cells, with proproliferative effects at low doses and antiproliferative (apoptosis-inducing) effects at high doses (Young et al. 2007). In another study, Young et al. (2008) reported on the biphasic responses of bioactive polyacetylenes, falcarinol and falcarindiol, present in carrots, celery, celeriac and other umbelliferous vegetables, on the stress responses in primary myotube cultures. Preincubation with low concentrations of both polyacetylenes prior to H_2O_2 exposure induced a cytoprotective effect, whereas higher concentrations had adverse effects. Earlier, Hansen et al. (2003) similarly reported biphasic activity of falcarinol in primary mammary epithelial cells, exerting stimulatory effects between 0.01 and 0.05 µg/ml and inhibitory effects between 1 and 10 µg/ml.

Anti-inflammatory Activity

Ethyl acetate extracts of celeriac-containing polyacetylenes inhibited proinflammatory cyclooxygenases (Cox-1 and Cox-2) at IC_{50} concentrations of 0.26 and 0.06 mg/mL, respectively (Metzger et al. 2013). Supercritical fluid extraction of dried celeriac root offered potential as an industrial scale enrichment process of anti-inflammatory polyacetylenes. The dried feed stock contained 4.5x's the amount of polyacetylenes compared to purple carrots. Optimal extraction conditions were low temperature (40 °C), high pressure (500 bar) and high ethanol co-solvent (20 % w/w). Pressure was more important for extraction of falcarinol and falcarindiol than temperature. Under optimal extraction conditions, 1.7 % of the starting dry weight or 47 % of the total lipids were extracted, and up to 43 % of falcarindiol was obtained compared to exhaustive ethyl acetate extraction.

Antiosteoporotic Activity

Mühlbauer et al. (2003) found that feeding rats 1 g/day of celeriac and 24 other items tested out of a total of 53 exhibited a protective effect against osteoporosis by significantly inhibiting bone resorption.

Immunomodulatory Activity

In a study of Apiaceous vegetables, at non-cytotoxic concentration, its related coumarins and flavonoids exhibited three types of immunomodulation including type 1 of phytohaemagglutinin (PHA), ConA and quercetin (increased lymphocyte activation and IFN-γ (interferon–gamma) secretion); type 2 of isopimpinellin (enhanced lymphocyte activation) and type 3 of

rutin, bergapten and xanthotoxin (elevated IFN-γ secretion) (Cherng et al. 2008). The augmentation of lymphocyte proliferation was closely correlated to an increase in the number of lymphocyte cells including $CD8^+$ T cells and activated peripheral blood mononuclear cells, whereas elevation of IFN-γ secretion was due to the activated $CD8^+$ T cells.

Allergy Problem

Occupational dermatitis from celeriac had been reported by Agathos (1980). The birch pollen allergen (Bet v 1)-homologous food allergen Api G1 was isolated and cloned from celeriac (Hoffmann-Sommergruber et al. 1996). Immunoblotting with sera from 22 patients with a positive double-blind placebo-controlled food challenge (DBPCFC) to celeriac confirmed the presence of known allergenic structures (Lüttkopf et al. 2000). The major allergen Api g 1 (16 kDa) was recognised by IgE from 13 of 22 patients (59 %). Another major allergen was CCD determined by IgE reactivity in 12 of 22 patients (55 %). Celery profilin, Api g 4, was recognised by IgE from 5 of 22 patients (23 %). Inhibition experiments with a purified carbohydrate moiety clearly showed that the IgE epitope mannose-xylose-fucose-glycan (Manalpha1-6[Xylbeta1-2] Manbeta1-4GlcNAcbeta1-4[Fucalpha1-3] GlcNAc) or a closely related structure was present in celeriac extract and was important in patients with clinical allergy to celery.

Bohle et al. (2003) found that humoral as well as cellular reactivity to the major celery/celeriac allergen Api g 1 was predominantly based on cross-reactivity with the major birch pollen allergen. The activation of Bet v 1-specific Th2 cells by Api g 1 may have consequences for birch pollen-allergic individuals. The nonoccupational sensitisation resulting from both direct and systemic contact with Apiaceae root vegetables (celeriac, parsnip and carrot) was apparently not caused by falcarinol (Paulsen et al. 2014). Twenty-four subjects with a positive double-blind, placebo-controlled food challenge result to celeriac, 20 atopic control subjects with birch pollen allergy who tolerated celeriac and 20 non-atopic subjects were enrolled in a study by Bauermeister et al. (2009). Component-resolved diagnosis allowed an increase in diagnostic sensitivity from 67 % to 88 % compared with extract-based diagnosis. Sensitisation to Api g 5 was attributable to its glycan moieties but did not interfere with diagnostic specificity. Husband et al. (2011) found the combination of high pressure and thermal processing to be an effective method to reduce the allergenicity of both apple and celeriac.

Other Uses

The growing plant has been reported to have insect repellent property; it repels the cabbage white butterfly so it is a good companion for tomatoes, *Allium* and *Brassica* vegetables (Riotte 1998).

Comments

Celeriac is readily propagated from seeds.

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Daucus carota

Scientific Name

***Daucus carota* L.**

Synonyms

Carota sylvestris (Mill.) Rupr., *Caucalis carnosa* Roth, *Caucalis carota* (L.) Crantz, *Caucalis daucus* Crantz, *Caucalis glabra* Forssk., *Daucus allionii* Link, *Daucus australis* Kotov (illeg), *Daucus blanchei* Reut., *Daucus brevicaulis* Raf., *Daucus carota* var. *brachycaulos* Reduron, *Daucus carota* f. *epurpuratus* Farw., *Daucus carota* f. *fischeri* Moldenke, *Daucus carota* f. *goodmanii* Moldenke, *Daucus carota* subsp. *hispidus* Masclef, *Daucus carota* var. *linearis* Reduron, *Daucus carota* var. *pseudocarota* (Rouy & E.G.Camus) Reduron, *Daucus carota* f. *roseus* Millsp., *Daucus carota* f. *roseus* Farw., *Daucus communis* Rouy & E.G.Camus, *Daucus communis* var. *pseudocarota* Rouy & E.G.Camus, *Daucus esculentus* Salisb., *Daucus exiguus* Steud., *Daucus gingidium* Georgi, *Daucus glaber* Opiz ex Celak., *Daucus heterophylus* Raf., *Daucus hispidus* (Arcang.) Gilib. (inval.), *Daucus kotovii* M.Hiroe, *Daucus levis* Raf., *Daucus marcidus* Timb.-Lagr., *Daucus maritimus* With., *Daucus montanus* Schmidt ex Nyman, *Daucus neglectus* Lowe, *Daucus nudicaulis* Raf., *Daucus officinalis* Gueldenst. ex Ledeb., *Daucus polygamus* Jacq. ex Nyman, *Daucus scariosus* Raf., *Daucus sciadophylus* Raf., *Daucus strigosus* Raf., *Daucus sylvestris* Mill., *Daucus vulgaris* Garsault (inval.), *Daucus vulgaris* Neck., *Tiricta daucoides* Raf.

Family

Apiaceae

Common/English Names

Bird's Nest, Bird's Nest Plant, Bishop's Lace, Carrot, Crow's Nest, Devil's Plague, Laceflower, Queen Anne's Lace, Rantipole, Wild Carrot

Vernacular Names

Afrikaans: Geelwortel

Arabic: Bazrul-Jazar, Fazar, Jazar, Tukhme Gazar

Brazil: Cenoura (Portuguese)

Bulgarian: Mopkob, Mórkov

Catalan: Apagallums, Bastanaga, Bastanaguera, Bestenaguera, Bufanaga, Bufanagas, Caps Blancs, Carolta, Carota, Juliverdina, Julivert Bord, Julivert De Galipau, Julivert De Gripau, Paraigüets, Pastanaga, Pastanaga D'ase, Pastanaga Marina, Pastinaga, Rosella Borda, Safanoria, Safranòria, Safranòria Borda, Xafarroni, Xirivia Borda

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Chinese: Chin Sun, Hong Cai Tou, Hong Da Gen, Hong Lu Fai, Hong Luo Bo, Hu Lu Fai, Ju Lobo, Hu Luo Bo, Huang Luo Bo, Jin Sun, Yang Hua Luo Bo
Croatian: Mrkva, Mrkvový
Czech: Mrkev Obecná, Mrkev Obecná Pravá
Danish: Gulerod, Gullerødder, Have-Gulerod, Karotter, Spisegulerod, Vild Gulerod
Dutch: Peen, Wortelen
Estonian: Metsporgand, Porgand
Finnish: Porkkana, Ruokaporkkana, Viljelty Porkkana
French: Carotte, Carotte Potagere, Carotte Sauvage, Chervis, Daucus Carotte
Gaelic: Curran, Mealbhacán
Georgian: Staphilo, Stapilo, Stapfilo
German: Echte Möhre, Gelbe Rübe, Karotte, Möhre, Mohrrübe, Rübe, Wilde Möhre
Greek: Karoto
Hebrew: Gezer, Gezer Ha-Ginna, Gezer Hagina, Gezer Haginah
Hungarian: Étkezési Sárgarépa, Murok, Sárgarépa, Vadmurok, Vadrépa
Icelandic: Gulrót
India: Gaajara (Bengali), Gajar (Gujarati), Gagar, Gajar, Gajar-Ke-Binj, Gajra, Gazar (Hindi), Bazrul-Jazar, Fazar, Jazar, Tukhme Gazar (Kannada), Gaajar, Gajar, Gajara, Gazara (Marathi), Antam Bulbal (Mizo), Dindiramodaka, Gajara, Gajida, Garijara, Garjara, Garjaram, Granthimula, Grinjana, Grnjana, Grunjana, Grunjanakam, Kanda, Na, Naranga, Narangavaraneshta, Pindamula, Pindika, Pitakanda, Pitamulaka, Shekhamulama, Shikha-Mulam, Shikhakanda, Shikhamulam, Shikhimula, Sumulaka, Supita, Svadumula, Varttula (Sanskrit), Gajjara-Kilangu, Gajjarakkilangu, Karattu, Karttukkilangu, Kattu-Kizhangu, Manjal-Mullangi, Manjalmullangi (Tamil), Gajjara-Gedda, Gajjaragedda, Pach-Cha-Mullangi, Pachchamullangi, Pita-Kanda, Pita-Kande, Pitakanda, Shikha-Mulamu, Shikhamulamu (Telugu), Gajor, Gazar (Urdu)
Indonesia: Bortol, Wertel, Wortel, Wortol (Javanese), Ortel, Wortel (Madurese), Bortol (Sundanese)
Italian: Carota, Carota Selvatica
Japanese: Ninjin
Khmer: Karôt
Kirgiz: Sabiz
Korean: Dang Geun, Hongdangmuu
Lithuanian: Morkos, Paprastoji
Luxembourgeois: Muurt, Wuerzel
Macedonian: Pitom Morkov
Malaysia: Karot, Lobak Merah
Maltese: Zunnarija
Majorcan: Bastanaga Borda, Bastenaga, Besteneguera, Botges, Botxas, Botxes, Fonollasa, Fonollassa
Nepali: Gajar
Norwegian: Dyrka Gulrot, Gulrot, Karotte, Villgurot
Persian: Gazar, Tukhme-Gazar, Tukhme-Zardak, Zadrak, Zardak
Philippines: Karot (Bikol), Karot (Bisaya), Karon (Iloko), Reaolacha (Spanish), Karot (Tagalog)
Polish: Marchew Ogrodowa, Marchew Siewna, Marchew Zwyczajna, Marchwe Zwyczajna, Ptasie Gniazdo
Portuguese: Biznaga Hortense De Flor Branca, Carote, Carrota, Cenoira, Cenoira Brava, Cenoura, Cenoura-Brava, Cenoura Ordinaria, Cinoira, Cinoura, Erva Coentrinha, Erva-Coentrinha, Escarrapiche
Romanian: Morcov, Morcov Comun, Morcov Comestibil
Russian: Moskov' Kul'turnaja, Morkov
Serbian: Šargarepa
Slovašcina: Mrkev Obecná, Mrkev Obecná Pravá
Slovencina: Mrkva Obyčajná
Spanish: Acenoria, Acenovia, Anís De Perro, Azanahoria, Bufanaga, Çanahoria, Carlota, Cenoria, Cenovia, Enredo, Guitama, Guitamo, Natero, Paraguas, Paragüicas, Pastinaca, Relumbraderas, Rompesacos, Sabuco, Safanovia, Zanahoria, Zanahoria Amarilla, Zanahoria Borde, Zanahoria Brava, Zanahoria Colorada, Zanahoria Forrajera, Zanahoria Naranjada, Zanahoria Silvestre, Zanahorias, Zanoria Borde, Zenoria
Swahili: Karoti
Swedish: Morot, Vildmorot
Thai: Khaerot
Turkish: Havuc, Pürcüklü

Vietnamese: Cà Rốt, Cà Rốt Dại
Welsh: Meddyglyn, Moron Gwylltion, Moron Y Meysydd, Moronen, Moronen Goch, Moronen Y Maes, Nyth Aderyn

Origin/Distribution

The cultivated carrot is domesticated from the wild carrot *Daucus carota* that is native to Europe and southwestern Asia. The domestic carrot has been selectively bred for its greatly enlarged and more palatable, less woody textured edible taproot. Asia Minor (eastern Turkey) and the inner Asiatic regions were identified by Vavilov (1926) as the centres of origin of cultivated carrot with Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan) as the basic centre of Asiatic kinds of cultivated carrots. The cultivated carrot is thought to originate from Afghanistan before the 900s, as this area is described as the primary centre of greatest carrot diversity (Mackevic 1929), Turkey being proposed as a secondary centre of origin (Banga 1963). On the basis of historical data, the first domesticated carrot roots were purple and yellow and recorded in Central Asia, Asia Minor, then in Western Europe and finally in England between the eleventh and fifteenth centuries (Banga 1963). Orange carrots were only documented in the fifteenth and sixteenth centuries in Europe suggesting that orange carotenoid accumulation may have resulted from a secondary domestication event (Banga 1957). White- and orange-coloured carrots were first described in Western Europe in the early seventeenth century (Banga 1963). Concomitantly, the Asiatic carrot was developed from the Afghan type, and a red type appeared in China and India around the eighteenth century (Laufer 1919; Shinohara 1984).

Analysis of allelic diversity of single nucleotide polymorphism (SNPs) data and in conjunction with historical data suggested an origin of domesticated carrot in Central Asia (Iorizzo et al. 2013). Among the wild carrots, those from Central Asia were genetically most similar to cultivated accessions. Furthermore, they found that wild carrots from North America were most closely related to European wild accessions.

Agroecology

Carrots are mostly cultivated as a cool season, temperate biennial crop with optimal growth between 15 and 18 °C, with a minimum of 7 °C and a maximum of 23 °C. Carrots can be grown in the tropics at high altitudes above 1,200 m or during the cool winter months in the subtropics. Production of the enlarged hypocotyl occurs most significantly when cool nights slow the plant respiration, allowing for an accumulation of carbohydrates. High soil temperatures, in excess of 25 °C, induce slow growth rates, fibrous roots and low carotene. Vernalisation of the plant at temperatures below 10 °C for several weeks initiates flower development and reduces carbohydrate accumulation in the hypocotyls.

Carrots flourish in well-drained, deep, friable, fertile soils. Muck and sandy loams are highly desired for carrot production. Optimum pH is 6.0–6.5. A regular supply of water is essential to obtain smooth and uniform roots.

Edible Plant Parts and Uses

Carrots are grown primarily for fresh consumption as julienne in salads, hors d'oeuvres, and as snacks and meal accompaniments. They are used in the preparation of soups, stews, stir fries, sauces, juices, curries and pies, and tender roots may be pickled. Grated carrots are used in carrot cakes, as well as carrot puddings, in jams and preserves with fruits. Carrot juice is also widely marketed, especially as a nutritious health drink, either stand-alone or blended with fruits and other vegetables such as celery. Carrots are puréed and used as baby food; dehydrated to make chips, flakes and powder; and thinly sliced and deep-fried, like potato chips.

Carotene is extracted from the root and used to colour margarines and is added to hen feed to modify egg yolk colour. Essential oil extracted from the seed is used for flavouring. Concentrated

carrot protein containing 15.4 % (w/w) carrot antifreeze protein was found to have strong anti-recrystallisation ability and textural properties for potential uses in the food industry (Zhang et al. 2007, 2008). The application of carrot concentrated protein in frozen dough was proved to be a promising improver/additive for frozen dough fermentation.

Carrot leaves are also edible as leaf vegetable but are only occasionally eaten by humans.

Botany

Annual or biennial erect herb up to 50 cm tall at the mature vegetative stage and up to 120 cm tall when flowering, with hispid, branched stems; taproot swollen, fleshy, straight, conical to cylindrical, 5–50 cm long and 2–5 cm in diameter at top, orange (most common), reddish violet, yellow or white (Plates 2, 3, 4, 5, 6 and 7). Leaves rosulate at base of the plant, triangular–ovate in outline, 22 cm long by 20 cm wide, cauline leaves, 26–30 cm long by 14–20 cm wide, alternating on flowering stems, 2–3 pinnate; exstipulate; petiole long, sheathed at base, petiole and rachis hispid; segments divided into oblong–lanceolate or linear–acute ultimate lobes, lacy in appearance (Plate 1). Upper cauline leaves are smaller and less divided. Inflorescence a terminal,

Plate 2 Carrot inflorescence

Plate 3 Carrots (common orange cultivar)

Plate 1 Carrot foliage

Plate 4 Harvested carrots

Plate 5 Carrots (white cultivar)

Plate 6 Carrots (purple cultivar)

Plate 7 L.S. of purple carrot

compound umbel (Plate 2) with numerous unequal rays, subglobose when in fruit; involucral foliaceous bracts 7–13, pinnatipartite or pinnatisect, with linear lobes. Flowers mainly bisexual, but male flowers also present, often one – few dark purple sterile flowers present in the centre of the umbel, 2 mm across, 5-merous; pedicel 0.5–1.5 cm long; calyx with small teeth or absent; petals free, suborbicular–ovate, white, sometimes yellow or pinkish; stamens five, free, twice as long as petals; ovary inferior, subglobose to oblong, bristly hairy, 2-celled, styles 2. Fruit an oblong–ovoid to oblong–ellipsoid schizocarp 2–4 mm long, at maturity splitting into two 1-seeded mericarps, primary ridges ciliate, secondary ridges with hooked spines.

Nutritive/Medicinal Properties

Root Nutrients/Phytochemicals

The proximate nutrient composition per 100 g edible portion of raw carrot was reported as: water 88.29 g; energy 41 kcal (173 kJ); protein 0.93 g; total lipid 0.24 g; ash 0.97 g; carbohydrate 9.58 g; total dietary fibre 2.8 g; total sugars 4.74 g; sucrose 3.59 g; glucose 0.59 g; fructose 0.55 g; starch 1.43 g; minerals, Ca 33 mg, Fe 0.30 mg, Mg 12 mg, P 35 mg, K 320 mg, Na 69 mg, Zn 0.24 mg, Cu 0.045 mg, Mn 0.143 mg, F 3.2 mg and Se 0.1 μg; vitamins, vitamin C 5.9 mg, thiamine 0.066 mg, riboflavin 0.058 mg, niacin 0.983 mg, pantothenic acid 0.273 mg, vitamin B6 0.138 mg, total folate 19 μg, total choline 8.8 mg, betaine 0.4 mg, vitamin A 16706 IU, vitamin A 835 μg RAE, vitamin K (phylloquinone) 13.2 μg, vitamin E (α-tocopherol) 0.66 mg, β-tocopherol 0.01 mg, β-carotene 8,285 μg, α-carotene 3,477 μg, lycopene 1 μg and lutein +zeaxanthin 256 μg; total saturated fatty acids 0.037 g; 16:0 (palmitic acid) 0.035 g; 18:0 (stearic acid) 0.002 g; total monounsaturated fatty acids 0.014 g; 16:1 undifferentiated (palmitoleic acid) 0.002 g; 18:1 undifferentiated (oleic acid)

0.012 g; total polyunsaturated fatty acids 0.117 g; 18:2 undifferentiated (linoleic acid) 0.115 g; 18:3 undifferentiated (linolenic acid) 0.002 g; and amino acids, tryptophan 0.012 g, threonine 0.191 g, isoleucine 0.077 g, leucine 0.102 g, lysine 0.101 g, methionine 0.020 g, cystine 0.083 g, phenylalanine 0.061 g, tyrosine 0.043 g, valine 0.069 g, arginine 0.091 g, histidine 0.040 g, alanine 0.113 g, aspartic acid 0.190 g, glutamic acid 0.366 g, glycine 0.047 g, proline 0.054 g and serine 0.054 g (USDA, ARS 2014). The following minor carbohydrates were found in carrot: *scyllo*-inositol (1.5–5.8 mg/g DW), sedoheptulose (D-*altro*-2-heptulose) (1.4–24.6 mg/g DW), *myo*-inositol (2.2–9.8 mg/ g) and mannitol (traces 1.3 mg/g) (Soria et al. 2009). Lipids extracted from carrot roots were found to contain phosphatidylethanolamine and phosphatidylcholine occurring as eight and seven molecular species, respectively (Gregor 1977).

Phan and Hsu (1973) found that concomitant with the elongation and the thickening of carrot root, there was an active synthesis of sugars, mainly sucrose, and carotenes, mainly β-carotene. The amounts of both groups peaked at the end of the third month after seeding and then plateaued. Roots contained 452.87 meq/100 g fw total phenols, 2.17 meq/100 g fw amino acids, 1.528 meq/100 g fw titratable acidity and 9.222 meq/100 g fw total acidity. Organic and amino acids increased slowly with age from rather low levels. In the 150 g FW root development stage, pyruvic acid (45.3 %) was most abundant, followed by isocitric (29.2 %) and malic (13.1 %) acids; other organic acids present were succinic (7.1 %), oxaloacetic (7.1 %), fumaric (1.7 %), citric (1.5 %) and glyoxylic (0.1 %). Phenolic compounds, abundant in the very young root, decreased rapidly during the first 3 months, then remained more or less constant up to harvest date. Carrots were found to contain malic, citric, succinic, fumaric, quinic and tartaric acids (Ruhl and Herrmann 1985). Depending on variety, growing stage and other factors, the total amount of organic acids in carrots is about 2,000–3,000 mg/kg (Vilisek 2013). After harvest isocitric and malic acids represent about 90–95 % of the total acids. The total content of isocitric and malic acids is approximately 1,000 mg/kg and 80 mg/kg, respectively. Tartaric acid (18–55 mg/kg), succinic acid (22–130 mg/kg), fumaric acid (5–8 mg/kg), quinic acid (42–60 mg/kg) and oxalic acids (100 mg/kg) were found in smaller quantities as were other acids in lower amounts. Nilsson (1987) found that sowing date had no influence on the concentration of sucrose, phosphorus, potassium, calcium and magnesium in carrot root dry matter up to 137 days from sowing. Carotene decreased only after the last sowing. Sucrose concentration of the roots increased throughout the periods studied irrespective of the time of sowing. The longer the growing period, the higher was the sucrose concentration. The concentration of hexoses decreased from the first harvest at 70 days to reach a constant level at about 130 days from sowing. Suojala (2000) found that the latter the harvest of carrots, the higher the content of soluble sugars, especially sucrose, tended to be. Total sugar and sucrose contents at the beginning of the harvest period were higher in the colder year than in the warmer year. The general pattern of increasing hexose and decreasing sucrose contents during storage was observed.

Carrot roots were reported to contain carotin and hydrocarotin (Husemann (1861). Six carotenes α-carotene, β-carotene, γ-carotene, ζ-carotene, β-zeacarotene and lycopene were detected in dark orange carrots (Simon and Wolff 1987). β-carotene accounted for 44–79 % of total carotenes, while β-, α- and ζ-carotenes comprised 94–97 % of total carotenes. Total carotene ranged from 63 to 548 ppm across lines and location/years. Carrots and other horticultural crops as a source of provitamin A carotenes provide a relatively inexpensive and readily sustainable approach to alleviate world vitamin A deficiency (Simon 1990).

Four major carotenoids were detected from coloured cultivars (yellow, purple or orange): lutein, α-carotene, β-carotene and its isomer 13*cis*β-carotene (Nicolle et al. 2004b). Yellow and purple varieties contained only lutein and β-carotene, whereas no carotenoids could be detected in white cultivars. The predominant carotenoid in all samples was β-carotene accounting for

43–71 % of the total carotenoids and α-carotene accounting for 17–22 % of total carotenoids. Lutein represented 29–41 % of the total carotenoids in yellow and purple carrots but a smaller portion (0.4–2.7 %) in other cultivars. Carotenoid levels in purple and yellow carrots varied from 469 to 605 μg/100 g, whereas ten times more carotenoids were found in orange carrots. The dark orange cultivar contained the highest amount of carotenoids, especially β-carotene (17 mg/100 g), whereas the purple cultivar was the poorest in β-carotene (0.32 mg/100 g) together with white cultivars. One yellow, one purple and one dark orange cultivars contained more than 600 μg/100 g of fresh weight vitamin E, while three others (one white cultivar and two orange cultivars) contained very low amount of α-tocopherol; their content was twofold lower than values given by food composition table. Vitamin C content varied from 1.44 to 5.75 mg/100 g in all 20 carrot varieties. The ascorbic acid content was much greater in the dark orange (four times), yellow (3.7 times) or white (3.4 times) cultivars than in orange carrots. Mean mineral content (mg/100 g fw) in all 20 cultivars was 579 mg K, Na 26.6 mg, Mg 12.1 mg, Ca 35.1 mg, Fe 0.79 mg and Zn 0.25 mg. According to Arscott and Tanumihardjo (2010), carrot varieties have undergone phenotypic recurrent selection (biofortification) to improve the profile of compounds such as augmenting provitamin content by >40 %. The most novel carrot produced to date is an orange–purple–red variety that not only contains provitamin A activity as α- and β-carotene but also contains anthocyanins and the nonprovitamin A carotenoid lycopene, of which both are potent antioxidants. Also, carrot contained phenolic constituents with a single aromatic ring (phenolic acids), mainly chlorogenic acid as potent antioxidants. Biofortified carrots of many colours not only provide vitamin A but may contribute to optimal health and utilise as a functional food.

Four major carotenoids were identified in five different coloured carrots (Surles et al. 2004). High β-carotene orange carrots were found to contain the greatest concentration of total carotenoids. Except for the white, all the carrots are a significant source of bioavailable carotenoids. Sensory evaluation showed the high β-carotene orange and white carrots to be favoured over the yellow, red, and purple carrots in both blind and non-blind treatments.

Total carotenoids (sum of lutein, lycopene, α-carotene and β-carotene) in μg/g DW was highest in dark orange carrot (1334.7 μg), followed by typical orange (816.3 μg), red (610 μg), purple orange (334.2 μg) and purple yellow (9,771 μg); yellow (52 μg) and white carrots (17.6 μg) contained small amounts of carotenoids (Sun et al. 2009). α- and β-carotenes were highest in dark orange followed by typical orange, more or less same in the others. Lutein content was higher in purple–yellow (26.6 μg) followed by yellow (19.8 μg), white (14.2 μg), purple–orange (9.04 μg), dark orange (5.53 μg) and orange (3.61 μg) carrot and lowest in red carrot (1.68 μg). Lycopene in red carrot (419.4 μg) was higher than the rest, dark orange (7.76 μg), orange (5.09 μg), purple orange (2.20 μg), yellow (0.32 μg) and white (0.35 μg). Most abundant carotenoid was β-carotene in dark orange (939.7 μg), followed by typical orange (579.3 μg), purple orange (239.5 μg), purple yellow (127.9 μg), yellow (30.1 μg) and white (2.81 μg). α-carotene was highest in dark orange (381.9 μg), typical orange (228.3 μg), purple orange (83.7 μg), purple yellow (18.9 μg), yellow (1.86 μg), red (1.74 μg) and white (0.46 μg).

Carotenoid content in six carrot cultivars ranged from 60 to 134 mg/kg (Matejkocá and Petriková 2010). Significantly higher levels of carotenoids were found in late and moderately late cultivars in comparison to early ones. Vitamin C content in these cultivars ranged from 54 to 132 mg/kg. Significantly higher contents of vitamin C were also found in the late cultivars. Thirty-day storage resulted in a significant reduction average of 47 % in vitamin C content. There was also a reduction in the carotenoid content, but to a lesser extent, on average of 11 %. Carrots, being one of the highest dietary sources of β-carotene and naturally high in the (all-*E*)-β-carotene isomer, were reported to have higher bioavailability, provitamin A activity and antioxidant capacity compared to *Z* (*cis*) isomers (Imsic et al. 2010).

Storing carrots at either 4 °C to simulate long-term storage or 20 °C to simulate marketing practices resulted in increases in (all-*E*)-β-carotene of 20.3 % after 3 days at 4 °C and 34.4 % after 14 days at 20 °C, respectively. The levels of Z isomers in raw carrots were low with (13Z)-β-carotene and (9Z)-β-carotene accounting for less that 1.8 % of the total β-carotene present. Levels of (9Z)-β-carotene decreased during storage at either temperature, whereas storage at 4 °C C resulted in a 109 % increase in (13Z)-β-carotene after 56 days. Cooking significantly increased the levels of (13Z)-β-carotene and (9Z)-β-carotene and resulted in the production of (15Z)-β-carotene, which was absent in raw carrots. Storage at 4 °C for 15 days or more prior to cooking reduced the susceptibility of (all-E)-β-carotene to thermal isomerisation during cooking, resulting in lower levels of all three Z-β-carotene isomers being generated, while storage at 20 °C for up to 21 days resulted in significantly higher levels of (all-*E*)-β-carotene before and after cooking but had no effect on Z-isomer production during cooking. They concluded from their study that, for the greatest health benefit, fresh carrots could be stored for up to 21 days at 20 °C or at 4 °C for up to 56 days without significant reduction in (all-*E*)-β-carotene and should be consumed raw or boiled for less than 15 minutes to limit Z-β-carotene isomer formation. When no additional B or Ca was supplied to carrot plants, an increase in the accumulation of α- and β-carotenes (33–50 %), vitamin C (45–70 %) and total phenolic acids was observed (Singh et al. 2012b). High calcium levels decreased the lycopene content in 'Nutri-Red' carrots. High levels of micronutrients production lead to an increase in carrot antioxidant properties.

Six novel pyranoanthocyanins were identified in black carrot (*Daucus carota* L. subsp. *sativus* var. *atrorubens*) juice (Schwarz et al. 2004). The two major compounds, namely, the vinylcatechol adducts of cyanidin 3-*O*-(6-*O*-feruloyl-β-D-glucopyranosyl)-(1→6)-[β-D-xylopyranosyl-(1→2)]-β-D-galactopyranoside and cyanidin 3-*O*-[β-D-xylopyranosyl-(1>2)]-β-D-galactopyranoside, respectively, were isolated. The four remaining pigments were characterised as the vinylphenol and vinylguaiacol adducts of cyanidin 3-*O*-[β-D-xylopyranosyl-(1→2)]-β-D-galactopyranoside, the vinylguaiacol adduct of cyanidin 3-*O*-(6-*O*-feruloyl-β-D-glucopyranosyl)-(1→6)-[β-D-xylopyranosyl-(1→2)]-β-D-galactopyranoside and the vinylcatechol adduct of cyanidin 3-*O*-(6-*O*-sinapoyl-β-D-glucopyranosyl)-(1→6)-[β-D-xylopyranosyl-(1→2)]-β-D-galactopyranoside. These compounds were formed during storage of the juice through the direct reaction of either caffeic, ferulic or coumaric acid with the respective genuine anthocyanins.

Three cyanidin glycosides have been identified in the black carrot: the known cyanidin 3-lathyroside and two new pigments, a cyanidin 3-xylosylglucosylgalactoside and its feruloyl derivative (Harborne 1976). Feruloyl and sinapyl derivatives of cyanidin 3-glucosylgalactoside occurred exceptionally in the stem of one subspecies, *maritimus*. Anthocyanins found in black carrots (*Daucus carota* subsp. *sativus* var. *atrorubens*) included cyanidin glycosides, peonidin glycosides and pelargonidin glycosides (Kammerer et al. 2003). Total anthocyanin amounts ranged from 45.4 to 17.4 g/kg dry matter in 15 black carrot cultivars (Kammerer et al. 2004b). Cyanidin 3-xylosyl(glucosyl)galactosides acylated with sinapic acid, ferulic acid and coumaric acid were detected as major anthocyanins in black carrot (*Daucus carota* subsp. *sativus* var. *atrorubens*) cultivars Antonina, Beta Sweet, Deep Purple and Purple Haze (Montilla et al. 2011). The anthocyanins detected included cyanidin 3-xylosylgalactoside, cyanidin 3-xylosyl (sinapoylglucosyl)galactoside, cyanidin 3-xylosyl (feruloylglucosyl)galactoside, cyanidin 3-xylosyl (*p*-coumaroylglucosyl)galactoside, cyanidin 3-xylosyl(caffeoylglucosyl)galactoside and cyanidin 3-xylosyl(*p*-hydroxybenzoylglucosyl) galactoside. Sucrose was predominant in all cultivars ranging from 39.5 % (cv. Afghan Purple) to 93.4 % (cv. Syria). Fructose (3.1–26.4 %) and glucose (3.5–34.2 %) were found in considerable smaller amounts with glucose. Unclarified black carrot juice, a rich source of anthocyanins, contained cyanidin 3-galactoside-xyloside-glucoside-ferulic acid as the major anthocyanin, followed by

cyanidin 3-galactoside-xyloside-glucoside-coumaric acid and cyanidin 3-galactoside-xyloside-glucoside (Türkyılmaz et al. 2012). After depectinisation, two more anthocyanins (cyanidin 3-galactoside-xyloside and cyanidin 3-galactoside-xyloside-glucoside-sinapic acid) were also identified. These results indicated that depectinisation and bentonite treatment had positive effect on the colour of black carrot juice, while gelatin–kieselsol treatment and pasteurisation had negative effect.

The anthocyanins found in seven coloured carrots were Cy-3-(2″-xylose-6-glucose-galactoside) (Cy3XGG), Cy-3-(2″-xylose-galactoside) (Cy3XG), Cy-3-(2″-xylose-6″-sinapoyl-glucose-galactoside) (Cy3XSGG),Cy-3-(2″-xylose-6″-feruloyl-glucose-galactoside) (Cy3XFGG) and Cy-3-(2″-xylose-6″-(4-coumaroyl) glucose-galactoside) (Cy3XCGG) (Sun et al. 2009). Cy3XSGG content in purple–orange carrot was higher than that in purple–yellow carrot. Cy3XG, Cy3XFGG and Cy3XCGG contents in purple–yellow carrots were higher than those in purple–orange carrots. Cy3XFGG and Cy3XG were highest in purple–orange carrot, and Cy3XSGG was highest in purple–yellow carrot. Total anthocyanin content in purple–yellow carrot was 17.3 μoll/g dw and 17.9 μMol/g in purple–orange carrot. Raman spectroscopy revealed detailed information regarding the relative content and distribution of carotenoids, α-, β-carotene, lutein and lycopene in carrot root (Baranska et al. 2006). The level of β-carotene was heterogeneous across root sections of orange, yellow, red and purple roots and in the secondary phloem increased gradually from periderm towards the core, but declined fast in cells close to the vascular cambium. α-carotene/lutein was deposited in younger cells with a higher rate than β-carotene, while lycopene in red carrots accumulated throughout the whole secondary phloem at the same level.

White carrot contained the highest content of volatiles, followed by orange, purple and yellow (Alasalvar et al. 2001). In total, 11, 16, 10 and 9 phenolic compounds were determined for the first time in orange, purple, yellow and white carrots, respectively, and the total concentration of all phenolic acids was the highest in purple carrots. Of these, chlorogenic acid was the most predominant phenolic compound in all carrot varieties. Differences in the relative sweetness, contents of vitamin C and α-carotene and β-carotene and certain flavour characteristics were observed among the coloured carrot varieties examined. Purple carrots contained 2.2 and 2.3 times more α- and β-carotenes (trace in yellow; not detected in white) than orange carrots, respectively. As regards to polyphenolic content, carrot was found to contain mainly hydroxycinnamic acid derivatives, namely, neochlorogenic acid (3′-caffeoylquinic acid), chlorogenic acid (5′-caffeoylquinic acid), 3′-*p*-coumaroylquinic acid, 3′-feruloylquinic acid, 3′4′-dicaffeoylquinic acid, 5′-feruloylquinic acid, 5′-*p*-coumaroylquinic acid, 4′-feruloylquinic acid, 3′5′-dicaffeoylquinic acid, 3′4′-diferuloylquinic acid and 3′5′-diferuloylquinic acid (Alasalvar et al. 2001). Phenolic acids were extracted from black carrot roots (*Daucus carota* subsp. *sativus* var. *atrorubens*) and black carrot juice concentrate (Kammerer et al. 2004a). Most of the compounds detected were identified as depsides composed of *p-coumaric*, caffeic and ferulic acids. Additionally, three hydroxybenzoic acid derivatives and one quercetin glycoside were detected. 5-*O*-Caffeoylquinic acid (chlorogenic acid) represented the predominant compound amounting to 657 mg/kg in the roots and 5,815 mg/kg in the concentrate. The specific fragmentation patterns of mono- and dihydroxycinnamoylquinic acids allowed the distinction of several stereoisomers. The presence of 4-*O*-caffeoylquinic acid and several further hydroxycinnamic acid esters, together with compounds not belonging to the depside type, was also found. Lako et al. (2007) found raw carrots to contain per 100 g: 16 mg GAE total polyphenols, <1 mg myricetin, <1 mg quercetin, traces of fisetin, traces of morin, traces of isorhamnetin, 4.4 mg α-carotene, 14 mg β-carotene and a total antioxidant capacity (TAC) of 2 mg TEAC/100 g. Carrot was found to contain 37.5 mg/kg luteolin (Miean and Mohaned 2001); <1.4 mg/kg luteolin, myricetin <1 mg/kg (Hertog et al. 1992), 3.1–14.3 mg/kg fw (Tsanova-Savova and Ribarova 2013); flavonol kaempferol 15.3 μg/g wet weight (Arai et al. 2000);

0.6 mg/100 g Fw ascorbic acid; total flavonoids 0.7 mg QE/100 g FW, flavonols quercetin 21 µg/100 g FW and kaempferol 72 µg/100 g FW and hydrophilic antioxidant capacity 276 µM TE/100 g FW in ORAC assay (Kevers et al. 2007). From the extracts of Ri T-DNA-transformed carrot roots, six flavonoids were isolated and identified: three flavonols (quercetin, kaempferol, rutin or quercetin 3-rutinoside) and three flavones (apigenin, chrysin and luteolin) (Rhlid et al. 1993). Three flavonols (quercetin, kaempferol, rutin or quercetin 3-rutinoside) and two flavones (apigenin, luteolin) were identified in carrot root exudates (Poulin et al. 1993). Flavonols like quercetin and kaempferol had been reported to have stimulatory effects on the hyphal growth of *Gigaspora margarita*, a vesicular–arbuscular mycorrhizal fungus. Domestically prepared carrot juice contained per ml juice 235 µg/ml caffeic acid, 194 µg/ml chlorogenic acid, 17.3 µg/ml quercetin and two dihydrochalcones: 219 µg/ml phloretin and 54.3 µg/ml phloridzin (Przybylska et al. 2007). In the case of carrot roots, the transgenic material (2,979 µg/g dw) was richer in phytochemicals than the normal roots (643 µg/g dw). Transgenic carrot roots contained 712 µg/g dw chlorogenic acid, 1,241 µg/g dw 4-hydroxybenzoic acid and 1,019 µg/g dw unknown phenol, while normal roots contained 373 µg/g dw chlorogenic acid and 270 µg/g dw 4-hydroxybenzoic acid. Rakcejeva et al. (2012) reported the following chemical composition of five hybrid carrots cultivated in Latvia: moisture content 86.95–90.15 %, soluble solids 6.10–10.3 °Brix, firmness 81.28–103.98 N, carotenoid 60.21–79.47 mg/100 g DM and total phenolic content 272.21–539.76 mg GAE/100 g DM. All hybrids contained gallic acid, caffeic acid, chlorogenic acid and catechin, and some hybrids also contained vanillin, ferulic acid and epicatechin.

Twenty-three volatile compounds were identified in the raw carrot (Heatherbell et al. 1971). Of these, diethyl ether, acetaldehyde, acetone, propanal, methanol, ethanol and β-phellandrene had not been previously reported in raw carrots. Acetaldehyde, sabinene, myrcene and terpinolene were considered important character-impact compounds in raw carrot aroma. Differences in volatile composition between canned, freeze-dried and raw carrot were found to be mainly quantitative rather than qualitative. Ethanethiol, dimethyl sulfide and dimethyl-substituted styrene compounds formed with canning. Canning resulted in an approximate 50 % loss of 'higher boiling' compounds; however, it produced an increase in 'lower boiling' compounds, particularly methanol, which increased from 0.05 to 60 ppm. Freeze-drying resulted in an approximate 75 % loss of total volatile content. Ethanethiol, dimethyl sulfide, acetaldehyde, octanal, 2-decenal and possibly dimethyl-substituted styrene compounds were deemed important in canned carrot flavour. Volatile terpenoids found in carrot roots included: α-pinene, β-pinene, myrcene, α-phellandrene, α-terpinene, limonene, γ-terpinene, terpinolene, bornyl acetate, β-caryophyllene, *E*-γ-bisabolene (Senalik and Simon 1986). Most carrot volatiles, in particular terpenoids (sabinene, β-pinene, β-myrcene, limonene, *trans*-caryophyllene, α-humulene, β-bisabolene and α-farnesene) decreased by at least 50 % within 60 seconds of blanching (Shamaila et al. 1996). Ratings on quality attributes of colour, texture, raw carrot aroma, sweetness, flavour and overall impression decreased with blanching time, while cooked carrot aroma increased. There were correlations between blanching times, flavour volatiles and sensory attributes. A total of 35 different volatile compounds were identified in carrots (Alasalvar et al. 1999). Of these, *trans*-ocimene, 2,5-dimethyl styrene, camphor, borneol, *α*-santalene, *α*-selinene, *γ*-elemene and *α*-zingiberene in raw carrots and propanol in stored carrots were identified for the first time. Major volatile compounds identified in raw carrots were *α*-pinene, sabinene, myrcene, limonene, *γ*-terpinene, terpinolene, *β*-caryophyllene and *γ*-bisabolene. Mono-and sesquiterpenes accounted for about 97 % of the total volatiles identified. Carrot volatiles did not change appreciably during the 28-day storage period at 5, 25 and 35 °C, except propanol that showed exponential increases at higher temperatures. No propanol was detected in fresh raw carrots. Cooking resulted in 88.6, 93.0 and 95.5 %

loss in total volatiles after cooking times of 10, 20 and 30 minutes, respectively.

Terpenoid volatiles, such as α-pinene, sabinene, β-myrcene, limonene, γ-terpinene, terpinolene, *trans*-caryophyllene and β-bisabolene, and several furan derivatives were found to contribute to aroma in dehydrated carrot root samples (Soria et al. 2008).

The orange carrot genotypes were characterised by having significantly higher intensities in carrot flavour and aroma, while the reverse was true for the yellow genotypes (Kreutzmann et al. 2008b). The purple genotype was characterised by having significantly higher intensity in sickenly sweet flavour and nutty flavour, and the red genotype was characterised by having significantly higher intensities in green aroma and flavour, bitterness and burning aftertaste. It was concluded that the isolated terpenes did correlate to the harsh flavour attributes. Thirty volatiles were found in the head space extract and 25 were identified, and monoterpenes and sesquiterpenes accounted for 99 % of total volatile mass. Major monoterpenes were α-pinene, sabinene, β-pinene, β-myrcene, γ-terpinene, terpinolene and limonene. Major sesquiterpenes were β-caryophyllene, α-humulene and (*E*)-γ-bisabolene. Also detected were estragole (*p*-allylanisole) and α-chamigrene which were not reported before. Other volatiles identified included α-thujene, camphene, α-phellandrene, β-phellandrene, (*Z*)-β-ocimene, (*E*)-β-ocimene, *p*-cymene, (*E*,*E*)-2,4-heptadienal, camphor, (*Z*)-β-farnesene, γ-cadinene, β-bisabolene, cuparene, γ-elemene, caryophyllene oxide and (−)-caryophyllene oxide.

Thirty-six volatile compounds were identified in the headspace; monoterpenes and sesquiterpenes accounted for about 98 % of the total volatile mass in all carrot cultivars (Kjeldsen et al. 2001). Loss of carrot volatiles during concentration of headspace samples under a stream of nitrogen was detected; losses among major monoterpenes in the concentrated samples varied from 16 % for *p*-cymene to >40 % for α-pinene as compared to non-concentrated samples. Losses among high-boiling sesquiterpenes varied from not detectable (β-caryophyllene, α-humulene and caryophyllene oxide) to approximately 7 % for (*E*)-γ-bisabolene and (*Z*)-γ-bisabolene. A total of 52 compounds were quantified, of which mono- and sesquiterpenes accounted for approximately 99 % of the total volatile mass (Kjeldsen et al. 2003). Phenylpropanoids constituted the second class of compounds, whereas the third class contained the fatty acid derivative octanal. Major volatile compounds were (−)-α-pinene, β-myrcene, (−)-limonene, (+)-limonene, (+)-sabinene, γ-terpinene, *p*-cymene, terpinolene, β-caryophyllene, α-humulene and (*E*)- γ-bisabolene and (*Z*)-γ-bisabolene. All volatiles had been previously isolated with exception of (+)-cuparene, thymohydroquinone dimethyl ether, a caryophyllene oxide isomer and 3-oxo-β-ionone. Other volatiles included (+)-α-pinene, eugenol, elemicin, myristicin, (−)-caryophyllene oxide, (*Z*)-γ-bisabolene, α-zingiberene, (*E*)-γ-bisabolene, (+)-borneol, santalene, (+)-α-terpinyl acetate, (*E*,*E*)-α-farnesene, (+)-valencene, (*E*)-β-farnesene, α-humulene, (*Z*)-β-farnesene, (+)-aromadendrene, thymol methyl ether, β-caryophyllene, (+)-bornyl acetate, (*E*)-α-bergamotene, (−)-camphor, (−)-α-copaene, 6-methyl-5-hepten-2-one, (*E*)-β-ocimene, (−)-β-phellandrene, α-terpinene, (−)-α-phellandrene, (−)-thujene, (−)-camphene, (−)-β-pinene, (+)-β-pinene, 4 unknown sesquiterpenes, two unknown compounds and an unknown monoterpene. A considerable increase in the concentration of mono- and sesquiterpenes was observed during refrigerated storage, whereas the concentration of terpenoids was around the same level during frozen storage. The major volatiles together with (+)-α-pinene, (−)-β-pinene, (+)-β-pinene, 6-methyl-5-hepten-2-one, (−)-β-bisabolene, beta-ionone, and myristicin had an odour sensation, which included notes of 'carrot top', 'terpene-like', 'green', 'earthy', 'fruity', 'citrus like', 'spicy', 'woody' and 'sweet'.

Yahyaa et al. (2013) found the volatile norisoprenoids farnesylacetone, α-ionone, and β-ionone accumulated in Nairobi, Rothild and Purple Haze carrot cultivars but not in Yellowstone and Creme de Lite in a pattern reflecting their carotenoid content. A cDNA encoding a protein with carotenoid cleavage dioxygenase activity, DcCCD1, was identified in carrot and may have a role in carrot flavour biosynthesis. Aroma extract dilution

analysis (AEDA) found linden ether with the highest flavour dilution (FD) factor among cooked carrot volatiles (Buttery and Takeoka 2013). Others with tenfold lower FD factors were β-ionone, eugenol, β-damascenone, (*E*)-2-nonenal, octanal (+myrcene) and heptanal. Compounds showing the highest odour activity values included β-damascenone, (*E*)-2-nonenal, (*E*,*E*)-2,4-decadienal, β-ionone, octanal, (*E*)-2-decenal, eugenol and *p*-vinylguaiacol.

Constituents identified in carrot root essential oil: α-farnesene (17.07 %), caryophyllene (10.91 %), 2-formylmethyl-4, 6, 6-trimethyl-bicyclo [3. 3. 1] hept-3-ene (4.15 %), 1, 2, 3, 4-tetrahydro-6,7-dimethyl-naphthalene (2.83 %), 1-methyl-4-(5-methyl-1-methylene-4-hexenyl)-(*S*)-cyclohexene (1.62 %), 1, 1, 4, 8-tetramethyl-*cis*, *cis*, *cis*-4, 7, 10-cycloundecatriene (1.12 %), 1-octadecene (0.64 %), 1-methyl-4-(1-methylethyl) -1, 4-cyclohexadiene (0.14 %), 1-methyl-4-(1-methylethylidene)-cyclohexene (0.88 %), acetic acid, 1, 7, 7-trimethyl-bicyclo [2. 2. 1] hept-2-yl ester (0.50 %), 1, 2, 3, 4, 4a, 5, 6, 8 a-octahydro-7-methyl-4-methylene-1-(1-methylethyl)-(1α, 4aβ, 8aα)-naphthalene (0.14 %), 2, 6-dimethyl-6-(4-methyl-3-pentenyl)-bicyclo [3. 1. 1] hept-2-ene (0.57 %), 7, 11-dimethyl-3-methylene-(*E*) -1, 6, 10-dodecatriene (0.58 %), 1, 2, 3, 5, 6, 8a-hexahydro-4, 7-dimethyl-1-(1-methylethyl)-(1*S*-*cis*)naphthalene (0.15 %), germacrene D (0.55 %), 5-(1, 5-dimethyl-4-hexenyl)-2-methyl-[*s*-(*R**, *S**)] -1, 3-cyclohexadiene (0.26 %), caryophyllene oxide (0.605), α,α, 4-trimethyl-benzene methanol (0.11 %), 1, 2, 3, 5, 6, 7, 8, 8a-octahydro-1, 4-dimethyl-7-(1-methylethenyl)-[1*S* -(1α, 7α, 8 aβ)]-azulene (0.11 %), α-bisabolol (0.27 %), 1, 2-diethyl-3, 4-dimethyl-benzene (0.22 %), 1, 2, 4-metheno-1H-cyclobuta[b]cyclo (32.29 %), 1, 9-heptadeca-diene-4, 6-diyne-3-ol (0.17 %), 6*Z*-2, 5, 5, 10-tetramethyl-undeca-2, 6, 9-trien-8-one (0.21 %), tricyclo[3. 3. 2. 0(3, 7)]decane (0.25 %), 6-bromo 1-hexene (0.11 %), 1, 2, 3, 4-tetrahydro-1, 1,6-trimethyl-naphthalene (1.01 %), 1, 2, 3, 4-tetrahydro-5, 7-dimethyl-naphthalene (0.17 %), α-methyl-(±) -2-naphthalene methanol (0.60 %), (*Z*, *E*) -2, 9-heptadecadiene-4, 6-diyn-8-ol (0.26 %), 3-nonen-5-one (0.38 %), bromo-cyclohexane (0.12 %) and 1H-imidazol-2-amine (0.17 %) (Wu et al. 2006).

Carrots contained a wide array of phytochemicals such as carotenoids, phenolics, phenolics, polyacetylenes, isocoumarins, sesquiterpenes and α-tocopherol (Metzger et al. 2008; Metzger and Barnes 2009). Of the 13 coloured carrot varieties, Deep Purple carrot had the highest concentration of total polyacetylenes, α-tocopherol and total phenolics and also contain anthocyanins. Commercial fresh market and baby orange carrots both had high concentrations of provitamin A carotenoids. The bioactive fraction of purple carrot extract was found to be rich in the polyacetylene compounds falcarindiol, falcarindiol 3-acetate and falcarinol.

A compound falcarindiol with the structure *cis*-heptadeca-1,9-diene-4,6-diyne-3,8-diol was isolated from root tissue extracts of *Daucus carota* (Garrod et al. 1978). Lund (1992) found that the previously reported compound falcarindiol 3-monoacetate consisted of a mixture of the 3-acetate and its allylic isomer, 1-acetoxy-heptadeca-2,9-diene-4,6-diyn-8-ol. A new phenylpropanoid, epilaserine oxide, was isolated along with six known compounds, laserine, 2-epilaserine, panaxynol, ginsenoyne K, (8 *E*)-1,8-heptadecadiene-4,6-diyne-3,10-diol and vaginatin (Yang et al. 2008). Polyacetylenes falcarindiol (FaDOH), falcarindiol 3-acetate (FaDOAc) and falcarinol (FaOH) were detected in carrot root extracts using high-performance liquid chromatography coupled with diode array detection (Christensen and Kreutzmann 2007; Purup et al. 2009). The average recovery rates were 99.2, 96.8 and 99.7 % for FaDOH, FaDOAc and FaOH, respectively. The amounts of polyacetylenes falcarinol, falcarindiol and falcarindiol 3-acetate in carrots varied significantly due to external factors (harvesting times, localities) and between stored and fresh samples (Kjellenberg et al. 2010). Kjellenberg et al. (2012) found the falcarinol/total polyacetylene ratio was positively correlated with the root size, the amount of sucrose and the sucrose/total soluble sugar ratio among both fresh and stored samples. Root size was inversely correlated with the amounts of falcarindiol and falcarindiol 3-acetate,

especially among stored samples. Stored carrots exhibited an inverse correlation between polyacetylenes and the amount of soluble sugar. At a falcarinol content at harvest below approximately 200 mg/kg dry weight, the amounts of all polyacetylenes increased during storage, but above that level the amounts of all polyacetylenes instead decreased. Pferschy-Wenzig et al. (2009) found the content of falcarinol [(Z)-heptadeca-1,9-diene-4,6-diyn-3-ol] ranged from 0.70 to 4.06 mg/100 g fresh weight in carrot roots of 27 different carrot genotypes.

The carrot phytoalexin, 6-methoxymellein, accumulated in carrot suspension culture when it was incubated with a partial hydrolysate of carrot cells obtained by pectinase or trypsin treatment (Kurosaki et al. 1984). Cultured carrot cells incubated with the phytoalexin formed three different metabolites: among them, two which accumulated in the medium, were identified as the β-glucoside of 6-methoxymellein and 6-hydroxymellein. Marinelli et al. (1990) isolated 6-methoxymellein, and 6-hydroxymellein, its presumed biosynthetic precursor, from carrot root slices infected with *Sclerotium rolfsii* and *Fusarium solani*. Elicitation of both 6-methoxymellein and 6-hydroxymellein synthesis was achieved also in carrot cell suspension cultures by direct addition of pectinolytic enzymes such as *Aspergillus niger* pectinase highly purified *Fusarium moniliforme* endo-polygalacturonase. Talcott and Howard (1999) reported that 6-hydroxymellein was preferentially detected inside the cells, while 6-methoxymellein was always found in the culture medium. Small-diameter carrot roots accumulated greater amounts of 6-methoxymellein in periderm tissue compared to large roots. De Girolamo et al. (2004) found that processing carrots into a puree resulted in 10–25 % greater extraction of 6-methoxymellein than grinding fresh carrot samples, whereas steam-cooked and thermally processed purees had 15 % greater extraction than unheated purees. 6-methoxymellein was found in 78 % of fresh and conventionally processed carrot products samples with levels ranging from 0.02 to 76 μg/g. They found that the levels of 6-methoxymellein in blanched carrots obtained by boiling water or steam treatment were reduced by 69 or 33 %, respectively, as compared to fresh carrots. No decrease in 6-methoxymellein levels was observed after maceration with pectinolytic enzyme preparations. A reduction of 6-methoxymellein by 85 or 94 % was obtained after the entire cycle of carrot juice processing, depending on the blanching procedure used.

A bitter principle identified as 3-methyl-6-methoxy-8-hydroxy-3, 4-dihydroisocoumarin was isolated from carrots (Dodson et al. 1956; Sondheimer 1957a, b). The concentrations of 3-methyl-6-methoxy-8-hydroxy-3,4-dihydro-isocoumarin (MMHD) formed in carrot roots inoculated with certain fungi or treated with indole-3-acetic acid, 2,4-dichlorophenoxyacetic acid or 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) were related to the amount of ethylene produced by the root tissue (Chalutz et al. 1969). The formation of dihydroisocoumarins, chromones (eugenin) and scopoletin was induced in carrot roots by storage in the presence of low concentrations of ethylene and by inoculation with various fungi (Coxon et al. 1973). Ethylene applied exogenously in concentrations above 0.3 ppm induced the formation of MMHD in carrot root discs. Continued production of MMHD required the continued presence of ethylene. Lafuent et al. (1989) found the rate of 8-hydroxy-3-methyl-6-methoxy-3, 4-dihydroisocoumarin. Formation increased with increasing ethylene concentrations (0.5–50 ppm) and with increasing temperatures (0–15 °C). No isocoumarin was detected in intact carrots stored in air. Exposure of carrots to 0.1 ppm ethylene at 5 C for 30 days resulted in little isocoumarin formation, whereas 0.5 ppm for 14 days induced over 20 mg/100 g peel, which could be easily detected sensorially. The isocoumarin contents of water stressed and unstressed whole carrots held for 30 days at 5 °C under 0.5 ppm ethylene were similar. Sliced carrots held under the same conditions showed a marked increase in isocoumarin levels, reaching 120 mg/100 g peel. Sarkar and Phan (1975) demonstrated that biosynthesis of 8-hydroxy-6-methoxy-3-methyl-3,4-dihydroisocoumarin (also called isocoumarin) and 5-hydroxy-7-methoxy-2-methylchromone (eugenin) in carrot

root tissues treated with ethylene must proceed via the acetate pathway. Seljåsen et al. (2001) found ethylene treatment of carrots caused an increase in 6-methoxymellein and the conversion of higher amounts of sucrose to fructose and glucose compared to control carrots stored in air. This corresponded to higher sensory scores for bitterness and terpene flavour and a lower score for sweetness. Principal component analysis showed a more expressed bitter taste, earthy flavour, green flavour, terpene flavour and aftertaste in the ethylene-treated carrots. Correlations were found between the sweet taste and the content of sucrose ($r=0.91$,) and between the contents of various terpenes (particularly γ-terpinene, limonene and caryophyllene) and terpene flavour, green flavour, aftertaste and bitter taste ($r \geq 0.72$). In the air-stored carrots, these off-flavours seemed to be masked by a high sucrose content. Carrot root concentrations of α- and β-pinene, myrcene, α- and γ-terpinene, limonene, *p*-cymene, terpinolene, caryophyllene, bornyl acetate, and 2-nonenal varied depending on the carrot line (Holley et al. 2000). Lines with the highest °Brix to terpinolene ratios indicating a higher degrees of sweetness (and lower bitterness).

The following bitter compounds were isolated from cold-stored carrots and commercial carrot puree: 3-methyl-6-methoxy-8-hydroxy-3,4-dihydroisocoumarin (6-methoxymellein), 5-hydroxy-7-methoxy-2-methylchromone (eugenin), 2,4,5-trimethoxybenzaldehyde (gazarin), (*Z*)-heptadeca-1,9-diene-4,6-diin-3,8-diol (falcarindiol), (*Z*)-heptadeca-1,9-diene-4,6-diin-3-ol (falcarinol) and (*Z*)-3-acetoxy-heptadeca-1,9-diene-4,6-diin-8-ol (falcarindiol 3-acetate) (Czepa and Hofmann 2003). Due to the low concentrations of <0.1 mg/kg and the high taste thresholds found for eugenin and gazarin, these compounds could be unequivocally excluded as important contributors to the bitter taste of carrots. Also based on the ratio of the concentration to the bitter detection threshold, it was clearly demonstrated that neither in fresh and stored carrots nor in commercial carrot puree did 6-methoxymellein contribute to the bitter off-taste. Contrariwise, the concentrations of falcarindiol in stored carrots and, even more pronounced, in carrot puree were found to be 9- and 13-fold above its low bitter detection concentration of 0.04 mmol/kg, thus demonstrating that this acetylenic diol significantly contributed to the bitter taste of the carrot products investigated. According to Czepa and Hofmann (2004), the isocoumarin 6-methoxymellein was not a key player imparting the bitter taste in carrots but bisacetylenic oxylipins (*Z*)-heptadeca-1,9-dien-4,6-diyn-3-ol; (*Z*)-3-acetoxy-heptadeca-1,9-dien-4,6-diyn-8-ol and (*Z*)-heptadeca-1,9-dien-4,6-diyn-3,8-diol (falcarindiol) contributed mainly to the off-taste. Besides the known bitter compounds, 6-methoxymellein, falcarindiol, falcarinol and falcarindiol 3-acetate, the following bitter new compounds were identified in carrots with low bitter recognition thresholds between 8 and 47 µmol/L: vaginatin; isovaginatin; 2-epilaserine oxide; laserine oxide; laserine; 2-epilaserine; 6,8-*O*-ditigloyl-6ss,8α,11-trihydroxygermacra-1(10) *E*,4 *E*-diene; 6-*O*-angeloyl-, 8-*O*-tigloyl-6ss,8α,11-trihydroxygermacra-1(10) *E*,4 *E*-diene; as well as 8-*O*-angeloyl-tovarol and α-angeloyloxy-latifolone (Schmiech et al. 2008). Besides the previously reported falcarinol, falcarindiol and falcarindiol 3-acetate, nine additional bisacetylenes were identified, among which six derivatives were reported for the first time in literature and three compounds were previously not identified in carrots (Schmiech et al. 2009). Potential bitter compounds like polyacetylenes, isocoumarins and phenolic acids were quantified in the peel and the corresponding peeled carrot of eight carrot genotypes ('Bolero', 'Mello Yello', 'Nairobi', 'Tornado', 'Purple Haze', 'Line 1', 'Line 2' and 'Line 3') representing extremes in sensory-perceived odour, flavour and taste (Kreutzmann et al. 2008a). Falcarindiol and a di-caffeic acid derivative were highly related to bitterness in contrast to falcarinol and other potential bitter compounds. Falcarindiol and the di-caffeic acid derivative were primarily present in the peel, whereas falcarinol was almost evenly distributed in the root. Investigation of bitterness revealed that high sugar content to some extent could mask the bitter perception of carrots.

Four sesquiterpenes daucane esters, 2α-acetyloxy-4β-hydroxy-6α-*p*-hydroxybenzoyloxy-dauc-8-ene,2α-acetyloxy-4β-hydroxy-6α-angeloyloxy-10β- hydroxybenzoyloxy-dauc-8-ene,2α-acetyloxy-4β-hydroxy-6α-angeloyloxy-10β-cinnamoyloxy-dauc-8-ene and fercomin; falcarindiol; ferulenol; and sitosterol glucoside were isolated from wild carrot roots (Ahmed et al. 2005).

The amount of wax extracted from the periderm of carrot root was 53.2 mg/kg of chloroform extractable material, equivalent to 74 % weight of chloroform extract or 29 μg/cm^2 was/surface area (Espelie et al. 1980). The composition of carrot wax comprised 2.8 % hydrocarbon, 0.7 % wax ester, 34 % fatty alcohol, 50 % fatty acids and 13 % unknown component. The total amount of even-chain components of suberin-associated hydrocarbons was 47 %. The proportion of even-chain alkanes from carrot leaf wax was 15 %. Fatty alcohols and/or fatty acids combined total for carrots were 6.5 %.

Rhamnogalacturonan II, a small complex pectic polysaccharide, was obtained by enzymatic liquefaction from carrot juice (Doco et al. 1997). Rhamnogalacturonan II contained the diagnostic sugars, apiose, 2-*O*-methyl-L-fucose, 2-*O*-methyl-D-xylose, aceric acid, 3-deoxy-D-manno-octulosonic acid (Kdo) and 3-deoxy-D-lyxo-heptulosonic acid (Dha). An alcohol-insoluble residue from carrot root was found to contain partially non-methyl esterified polysaccharides (Needs et al. 1998). Digestion with driselase gave small amounts of acidic oligosaccharides, and alkaline hydrolysis gave more acidic 1,4-linked oligogalacturonic acids as products. These components appeared to contain non-methyl galacturonoyl esters, and the predominant component was shown to be a monomethyl-esterified, singly acetylated tetragalacturonic acid. The majority of the polymer fractions obtained from carrot root cell walls comprised pectic polysaccharides, with varying quantities of neutral sugars (arabinose and galactose) (Kang et al. 2008). Hemicellulosic polymers were generally found only in the strong alkali extracts (4 M KOH). *p*-OH-benzoic acid was the predominant phenolic ester, and *p*-OH-benzaldehyde was also detected in the fractions at much lower levels. *p*-OH-benzoic acid was associated predominantly with the branched pectic polysaccharides, in contrast to the *p*-OH-benzaldehyde.

Sturm et al. (1995) found that the genes for isoenzymes I and II of soluble acid β-fructofuranosidase (sI, sII) were mainly expressed in roots, sI predominating in primary roots and sII in developing taproots. Developing taproots contained only transcripts for sII and for sucrose synthase (ss). The expression of the gene for cell wall β-fructofuranosidase (cwβF) was development specific but not organ specific; high transcript levels were only found in plants with primary roots, with about equal amounts in leaf lamina, petioles and roots. Oligogalacturonate hydrolase was isolated from carrot roots (Stratilová et al. 2005). Its molecular mass, isoelectric point, glycosylation as well as cleavage of pectate from the nonreducing end corresponded to an exopolygalacturonase. The affinity of this enzyme to the substrates increased with the increasing degree of polymerisation, and the difference was observed only in the maximal ratio of catalysis of oligomeric and polymeric substrates.

Pectin methylesterase isolated from black carrot showed very high activity in a broad pH range of 6.5–8.5, with the optimum pH occurring at 7.5 (Ünal and Bellur 2009).

A 36 kDa antifreeze protein, localised in the apoplast, was isolated from the taproot of cold-acclimated carrot plants (Smallwood et al. 1999). This protein inhibited the recrystallisation of ice and exhibited thermal–hysteresis activity. The polypeptide behaved as a monomer in solution and was N-glycosylated. Meyer et al. (1999) isolated a encoding an antifreeze protein (AFP) from carrot. The carrot AFP was highly similar to the polygalacturonase inhibitor protein (PGIP) family of apoplastic plant leucine-rich repeat (LRR) proteins.

Cell Tissue/Suspension Culture Phytochemicals

Phosphatidylcholine, phosphatidylethanolamine, phosphatidylinositol and triacylglycerol were the main lipid components detected in carrot suspension

culture cells (Kleinig and Kopp 1978). Oleosomes (lipid droplets) isolated from carrot suspension culture cells were found to contain mainly of triacylglycerols (>97 %), free fatty acids about 1 %, phospholipid >0.05 % and very little protein (1–2 %) (Kleinig et al. 1978). The fatty acid pattern (%) of oleosomal triacylglycerols and total polar lipids, respectively, comprised: 14:0 (1.7 %, 0.7 %), 16:0 (24.1 %, 25.1 %), 16:1 (0 %, trace), 18:0 (12.9 %, 8.1 %), 18:1 (1.2 %, 0.3 %), 18:2 (53.6 %, 59.2 %) and 18:3 (6.4 %, 6.4 %). The fatty acid pattern of triacylglycerols was very similar to that of polar cellular membrane lipids. The major fatty acids detected at five embryo stages following induction of embryogenesis in carrot cultures were C16:0, C18:0, C18:1, C 18:2 and C18:3 (Warren and Fowler 1979). Quantitative rather than qualitative changes in fatty acid content were observed, although globular embryos had some fatty acids of long (C20 and above) chain length not observed in earlier (small meristematic cell stage, large vacuolated cell stage) or later embryo (heart and torpedo) stages. Embryogenic carrot cultured cells were shown to synthesise putrescine from exogenously supplied [(14)^{C}]arginine at twice the rate of control non-embryogenic cells (Montague et al. 1979). The activity of arginine decarboxylase, an important enzyme in the synthesis of putrescine, was found to be elevated by as much as twofold in embryogenic cells. A nitrogen-containing tertiary base was isolated from carrot seeds (Gambhir et al. 1979). Soluble esterases were identified in carrot, four carboxylesterases and two arylesterases (Carino and Montgomery 1968). Acetyl, propionyl and n-butyryl esters of phenol, sodium 2-naphthol-6-sulfonate and glycerol and n-hexyl ester of sodium 2-naphthol-6-sulfonate were hydrolyzed by carrot esterases. Carrot esterases showed maximal activity with phenyl esters, while the esters of sodium 2-naphthol-6-sulfonate and triglycerides were hydrolyzed at slower rates. Polyphenol oxidase was purified from carrot cell cultures (Söderhäll and Söderhäll 1989). N-acetyl glutamate kinase (NAGK) was purified and characterised from *Daucus carota* suspension cultures (Lohmeier-Vogel et al. 2005). Carrot NAGK was shown to have a subunit molecular weight of 31 kDa and form a hexamer. Reduction of acetophenone by carrot hairy root cultures afforded (*S*)-phenylethanol in high yield (96 %) and excellent enantiomeric excess (ee > or = 98 %) (Caron et al. 2005). Aromatic ketones, keto esters and a simple aliphatic ketone were reduced with good stereoselectivity (ee = 62–98 %) and moderate to high chemical yields (25–90 %).

The product of gitoxigenin transformation by *Daucus carota* cell suspension culture was isolated from culture filtrates and identified as 5β-hydroxygitoxigenin (Veliky et al. 1980). Four anthocyanins were found in the carrot cell culture: cyanidin 3-glucogalactoside, cyanidin-3,5-digalactoside, cyanidin 3-glucoside and cyanidin 3-galactoside (Hemingson and Collins 1982). Cyanidin 3-(sinapoylxylosylglucosylgalactoside) was identified as a major anthocyanin in carrot cell tissue culture (Harborne et al. 1983). Microsomal preparations from carrot cell suspension cultures catalysed the formation of *trans*-5-*O*-caffeoyl-D-quinate (chlorogenate) from *trans*-5-*O*-(4-coumaroyl)-D-quinate, and *trans*-5-*O*-(4-coumaroyl) shikimate was converted to about the same extent to *trans*-5-*O*-caffeoylshikimate (Kühnl et al. 1987). *trans*-4-*O*-(4-coumaroyl)-D-quinate, *trans*-3-*O*-(4-coumaroyl)-D-quinate, *trans*-4-coumarate and *cis*-5-*O*-(4-coumaroyl)-D-quinate did not act as substrates. They found that the biosynthesis of the predominant caffeic acid conjugates in carrot cells occurred via the corresponding 4-coumaric acid esters. Thus, in this system, 5-*O*-(4-coumaroyl)-D-quinate could be seen as the final intermediate in the chlorogenic acid pathway.

A trypsin inhibitor with a molecular weight of about 12,800 was purified from embryogenic carrot cells (Carlberg et al. 1987). The protease inhibitor was heat stable and inhibited trypsin but had no activity towards chymotrypsin or subtilisin. An autocatalytic protein-glycosylating glycosyltransferase enzyme (40,000 Da) was purified from carrot cell suspension (Quentmeier et al. 1987). Dark-grown carrot tissue cultures were found to contain both protein components of the NADP/thioredoxin system–NADP–thioredoxin reductase and the thioredoxin characteristic of

heterotrophic systems, thioredoxin H (Johnson et al. 1987). Thioredoxin H a 12-kdalton (kDa) acidic protein was capable of activating chloroplast NADP–malate dehydrogenase more effectively than fructose-1,6-bisphosphatase. NADP–thioredoxin reductase was partially purified and found to be an arsenite-sensitive enzyme composed of two 34-kDa subunits. Protein preparations from cell suspension cultures of an Afghan carrot containing the enzymes 1-*O*-hydroxycinnamoyl-β-glucose–cyanidin 3-*O*-(2″-*O*-xylosyl-6″-*O*-glucosylgalactoside) 6′-*O*-hydroxycinnamoyltransferases catalysed the formation of acylated anthocyanins from a cyanidin triglycoside isolated from the carrot cultures using 1-*O*-sinapoyl-, 1-*O*-feruloyl- and 1-*O*-(*p*-coumaroyl)-β-glucose as acyl donors (Gläßgen and Seitz 1992). Thuleau et al. (1993) found solubilised proteins from carrot cell membrane-bound calcium channel blockers and form calcium-permeable ion channels. Their results suggested that the 75-kDa Ca^{2+} channel blocker-binding protein from carrot cells played a role in channel sensitivity to Ca^{2+} channel inhibitors and may constitute one of the components of Ca^{2+} channels in higher plants. A soluble phosphatidylinositol 4-kinase (PI 4-kinase) was found in carrot suspension culture cells (Okpodu et al. 1990). The enzyme was found to have a molecular weight of 83,000 (Okpodu et al. 1995). The isolated lipid kinase phosphorylated phosphatidylinositol but not lysophosphatidylinositol or phosphatidylinositol.

A highly enantioselective preparation (92–99 % enantiomeric excess, 100 % conversion) of various 4-aryl-2-hydroxy but-3-enoic carboxylic acid esters from the corresponding 4-phenyl-2-keto but-3-enoic acid esters was found to be mediated by carrot plant cell cultures under mild and environmentally benign conditions in aqueous medium (Baskar et al. 2004). *Agrobacterium rhizogenes*-induced hairy root cultures of *Daucus carota* showed a considerable amount of *p*-hydroxybenzoic acid accumulation both in cytosol and in the cell wall (Sircar et al. 2007). This phenolic acid finds application in food, pharmaceutical and polymer industries. Studies by Sircar and Mitra (2009) suggested that *p*-hydroxybenzaldehyde might be the immediate precursor in *p*-hydroxybenzoic acid biosynthesis. In-vitro conversion of *p*-coumaric acid to *p*-hydroxybenzoic acid with *p*-hydroxybenzaldehyde as intermediate using cell-free extract provided an unequivocal support for CoA-independent and non-beta-oxidative route of *p*-hydroxybenzoic acid biosynthesis in carrot hairy roots.

Six anthocyanins were isolated from cell suspension cultures of an Afghan carrot cultivar. The structures of these compounds were elucidated as cyanidin 3-*O*-lathyroside, cyanidin 3-*O*-(2″-*O*-β-D-xylopyranosyl-6″-*O*-β-D-glucopyranosyl-β-D-galactopyranoside) and the latter acylated with 4-coumaroyl, feruloyl, 4-hydroxybenzoyl and sinapoyl (Gläßgen et al. 1992). The major anthocyanins accumulated by an Afghan cultivar of *Daucus carota* were cyanidin 3-(xylosylglucosylgalactosides) acylated with sinapic or ferulic acid (Rose et al. 1996). They detected two enzymatic glycosylation reactions in the protein preparations from carrot cell suspension cultures. The first reaction was a galactosyl transfer catalysed by UDP-galactose–cyanidin galactosyltransferase (CGT) resulting in cyanidin 3-galactoside. The putative second reaction involved the formation of cyanidin 3-(xylosylgalactoside) catalysed by UDP-xylose–cyanidin 3-galactoside xylosyltransferase (CGXT). In both cases, a molecular mass of 52 kDa was determined, indicating that the native protein was a monomer of 52 kDa. Feeding 15 cinnamic and benzoic acids to anthocyanin-producing wild carrot cell cultures one at a time afforded 17 anthocyanins differing only in the acyl group (Baker et al. 1999). The extra two were anthocyanins acylated with 4-chlorobenzoic acid and 4-trifluoromethylbenzoic acid. They found that the majority of acids used by carrot cell cultures to acylate anthocyanins were mediated via the 1-β-D-glucose ester pathway.

Studies indicated the presence of cyanidin 3-lathyroside [cyanidin 3-0{β-D-xylopyranosyl (1→2) β-D-galacto pyranoside}] (90 %) and cyanidin 3-β-D-glucopyranoside (10 %) in carrot callus cultures, whereas only cyanidin

3-lathyroside (0.05 %) was found in the explant carrot (Narayan and Venkataraman 2000). The main anthocyanins detected in cultivars of black carrot (*Daucus carota* L. subsp. *sativus* var. *atrorubens*) Antonina and Purple Haze were found to be five cyanidin-based anthocyanins: cyanidin 3-xylosylglucosylgalactoside, cyanidin 3-xylosylgalactoside and the sinapic, ferulic and coumaric acids derivative of cyanidin 3-xylosylglucosylgalactoside (Algarra et al. 2014). The anthocyanins present in the black carrots were essentially acylated, and their levels were found to correspond to 25 % and 50 % of the total phenolic content for the Purple Haze and Antonina cultivars, respectively.

Total lipids constituted approx. 0.2 % of fresh weight in carrot callus and suspension culture but approx. 0.5 % in heart- and torpedo-shaped embryoids (Dutta and Appelqvist 1989). Petroselinic acid (*cis*-6–8:1), accounting for approx. 70 % of carrot seed oil, was not present in callus, suspension culture (0 time) and globular embryoids. Petroselinic acid first occurred in the heart-shaped embryoids and reached a maximum level of 1.4 % in the triacylglycerols of torpedo-shaped embryoids. The major fatty acids invariably in all kinds of tissues were linoleic (18:2) and palmitic (16:0) acids, and the minor ones were stearic (18:0), oleic (*cis*-9–18:1), vaccenic (*cis*-11–18:1) and linolenic (18:3) acid. Different cultural conditions could not boost petroselinic acid accumulation but did increase triacylglycerol content in total lipids in embryoids with a maximum level of approx. 17 mg triacylglycerols per g fresh weight. Abscisic acid, sorbitol and their combination gave the maximum level of total lipids per g fresh weight; approx. 75 % of the lipids were triacylglycerols.

Flower/Fruit/Seed Phytochemicals

From the fruits the following compounds were isolated: two guaiane-type sesquiterpene glycosides, 11-*O*-acetyl-torilolone 8-*O*-β-D-glucopyranoside and 1β-hydroxytorilolone 11-*O*-β-D-glucopyranoside (Fu et al. 2010a); two new guaiane-type sesquiterpenoids containing an interesting epoxy unit, daucuside and daucusol (Fu et al. 2010c); a new guaiane-type sesquiterpene glycoside, torilolone 8-*O*-β-D-glucopyranoside (1), together with a known analogue compound, torilolone 11-*O*-β-D-glucopyranoside (Fu et al. 2010b) and a new sesquiterpene named as daucucarotol with the structure (1α,5α,8α,10β)-decahydro-6α-hydroxy-8α,8α,6β-trimethyl-1,8-naphthalene-dimethanol (Fu et al. 2009). Two new sesquiterpenes, 11-(acetyloxy) torilolone (**1**) and 1β-hydroxytorilolone (**2**), were isolated from carrot fruit (Yi et al. 2009).

A new flavone glycoside, apigenin 7-*O*-β-D-galactopyranosyl-(1→4)-*O*-β-D-mannopyranoside, and apigenin 4′-*O*-β-D-glucoside and kaempferol 3-*O*-β-D-glucoside were isolated from carrot seeds (Gupta and Niranjan 1982). 2,4,5-trimethoxybenzaldehyde, oleic acid, *trans*-asarone and geraniol were isolated from carrot seeds (Momin et al. 2003). Daucic acid, carotol and daucol were isolated from carrot seed oil (Ashraf et al. 1977). Studies by Lichtenthaler et al. (2003) found (−)-daucic acid to have D-*lyxo*-configuration rather than the previously assigned D-*xylo* stereochemistry. Configurational identity in the pyranoid rings of (−)-daucic acid and 3-deoxy-D-manno-octulosonate (KDO), together with available biosynthetic evidence on chelidonic acid, a leaf closing factor, suggested a joint, KDO 8-phosphate 8-P-based pathway, for their biosynthesis in plants.

Constituents identified in carrot flower essential oil included: (1*R*)-α pinene (12.64 %), caryophyllene (9.62 %), β-myrcene (9.15 %), 3,7-dimethyl-1,3,7-octatriene (7.15 %), (+)-*epi*-bicyclosesquiphellandrene (6.19 %), limonene (5.15 %), 3-carene (3.66 %), camphene (2.79 %), γ-elemene (2.71 %), 1,1,4,8-tetramethyl-*cis*,*cis*,*cis*-4,7,10-cycloundecatriene (2.17 %), 7,11-dimethyl-3-methylene-(*E*)-1,6,10-dodecatriene (1.15 %), 4-methylene-1-(1-methylethyl-cyclohexene (1.13 %), 1-methyl-4-(1-methylethylidene)-cyclohexene (1.01 %), 2,6,6-trimethyl (±)-bicyclo[3.1.1]hept-2-ene (0.47 %), (+)-4-carene (0.10 %), 1-methyl-3-(1-methylethyl) benzene (0.11 %), 1-methyl-4-(1-methylethyl)-1,4-cyclohexadiene (0.65 %), 2-methyl-6-methylene-oct-3,7-dien-2-ol (0.16 %), 4-methyl-1-(1-methylethyl)-3-cyclohexen-1-ol (0.29 %), α,α,

4-trimethyl-3-cyclohexene-1-methanol (0.35 %), acetic acid, 1, 7, 7-trimethyl-bicyclo [2. 2. 1] hept-2-yl ester (0.13 %), 4-(2-butenyl)-1, 2-dimethyl-(*E*)-benzene (0.08 %), 1, 3, 5-trimethyl-2-(1-methylethenyl)-benzene (0.11 %), 3, 7, 7-trimethyl-bicyclo [4-1. 0] hept-2-ene (0.16 %), 1, 5, 5-trimethyl-6-methylene-cyclohexene (0.15 %), copaene (0.26 %), 1a, 2, 3, 5, 6, 7, 7a, 7b-octahydro-1, 1, 7, 7a-tetramethyl-[1a*R*-(1aα, 7α,7aα, 7bα)] -1H -cyclopropa[α]naphthalene (0.25 %), 1, 2,3,4,4a,5,6,8a-octahydro-7-methyl-4-methylene-1-(1-methylethyl) -(1α, 4aβ, 8aα)-naphthalene (0.44 %), octahydro-3,8,8-trimethyl-6-methylene-[3R-(3α, 3aβ,7β,8aα)]-1H-3a,7-methanoazulene (0.22 %), 1H-benzocycloheptene-2, 4 a, 5, 6, 7, 8, 9, 9a-octahydro-3, 5, 5-trimethyl-9-methylene-(4 a*S-cis*) (0.36 %), 6-dimethyl-6-(4-methyl-3-pentenyl) -bicyclo [3. 1. 1] hept-2-ene (0.25 %), 1, 2, 3, 5, 6, 8 a-hexahydro-4, 7-dimethyl-1-(1-methylethyl) -(1*S-cis*) -naphthalene (0.52 %), 3, 7-dimethyl-(*Z*)-1, 3, 6-octatriene (2.11 %), 4, 11, 11-trimethyl-8-methylene-[1*R*-(1*R**, 4*Z*, 9*S**)]-bicyclo[7- 2.0]undec-4-ene (0.39 %), carotol (16.39 %), decahydro-4a-methyl-8-methylene-2-(1-methylethyl) -[1R-(1α, 2β, 4aβ,8aα)]-1-naphthalenol (0.17 %), τ-muurolol (0.53 %), 1, 2, 4-trimethoxy-5-(1-propenyl) -(*Z*)-benzene (0.34 %), α-cadinol (0.68 %), 2, 7, 7-trimethyl-bicyclo[3. 1. 1] hept-2-en-6-one (0.12 %), α-bisabolol (0.49 %), 1, 2, 3, 4, 4a, 5, 6, 8a-octahydro-4a, 8-dimethyl-2-(1-methylethenyl) -[2*R* -(2α, 4aα, 8aβ)]-naphthalene/-selinene (2.05 %), 3, 7, 11-trimethyl-(*Z*, *E*) -2, 6, 10-dodecatrien-1-ol (0.03 %), (*E*, *E*)-7, 11, 15-trimethyl-3-methylene-hexadeca-1, 6, 10, 14-tetraene (0.10 %), 1, 2, 3, 4-tetrahydro-5, 6-dimethyl-naphthalene (0.42 %), 1, 2, 3, 4-tetrahydro-6,7-dimethyl-naphthalene (0.24 %), 1, 2, 3, 4-tetrahydro-5, 7-dimethyl-naphthalene (1.61 %), phytol (0.33 %), 1-(2-butenyl)-2,3-dimethyl-benzene (0.27 %), heneicosane (0.10 %), 3,3,6-trimethyl-1,5-heptadien-4-one (0.18 %), pentacosane (0.15 %), heptacosane (0.28 %) and nonacosane (0.14 %) (Wu et al. 2006).

Daucus carota poly(A)-binding proteins, DcPAB, was found to be differentially expressed under different conditions suggesting a potently unique role in the development of carrot somatic embryo (Lin et al. 2003). 4-hydroxybenzyl alcohol (4HBA) accumulated in carrot flowers and immature and mature fruits, but not in vegetative tissues (Kobayashi et al. 2003). The concentration of 4HBA was highest after flowering, when the zygote developed into the early globular-stage embryo. 4HBA accumulation then decreased with seed development. Exogenous application of 4HBA to immature carrot fruits inhibited seed formation. Many 4HBA-treated seeds did not include a mature embryo. D, L-iditol, kaempferol 3-*O*-B-glucoside, laserine and a mixture of stigmasterol and sitosterol were isolated from carrot flower (Akgul et al. 2009). The main components in the Sardinian essential oil of flowering and mature carrot umbels with seeds were β-bisabolene (17.6–51.0 %) and 11-α-(H)-himachal-4-en-1-β-ol (9.0–21.6 %); instead, the oils from Portuguese samples were predominantly composed of geranyl acetate (5.2–65.0 %) and α-pinene (3.5–37.9 %) (Maxia et al. 2009). Supercritical extracts contain lower amounts of monoterpenes and higher amounts of sesquiterpene hydrocarbons. The main components of the essential oil of carrot flowering and mature umbels with seeds from Sejnane were eudesm-7(11)-en-4-ol (8.2–8.5 %), carotol (3.5–5.2 %), sabinene (12.0–14.5 %), α-selinene (7.4–8.6) and 11-α-(H)-himachal-4-en-1-β-ol (12.7–17.4 %), whereas the oils from Tunis were predominantly composed of elemicin (31.5–35.3 %) and carotol (48.0–55.7 %) (Marzouki et al. 2010). Thirty-six compounds were identified in carrot seed essential oils, with a predominance of sesquiterpene hydrocarbons in most samples (22.63–89.93 % of the total oil composition) (Rokbeni et al. 2013). The main volatile compounds identified were β-bisabolene (mean content of 39.33 %), sabinene (8.53 %), geranyl acetate (7.12 %) and elemicin (6.26 %). Carrot umbel essential oil yield varied from 0.7 to 1.8 % (v/w) during umbel ontogeny (Verma et al. 2014). Thirty-four constituents, forming 94.5–97.9 % of the total compositions, were identified. The essential oil composition was characterised by high proportions of monoterpenoids (35.9–81.3 %) and sesquiterpenoids (15.1–62.0 %). Major constituents

of the essential oils were carotol (10.2–58.5 %), α-pinene (21.2–41.2 %), myrcene (6.4–14.1 %), limonene (4.4–12.7 %) and sabinene (0.2–5.3 %).

The sesquiterpenoid monoethylenic tertiary alcohol carotol isolated from carrot essential oil was found to have the structure Δ^2-3,10-dimethyl-6-isopropylbicyclo-(0,3,5)-decen-6-ol (Chiurdoglu and Descamps 1960). A sesquiterpene ether, carota-1,4-β-oxide, was isolated from the essential oil of carrot seeds (Dhillon et al. 1989). A new daucane-type sesquiterpene alcohol, *trans*-dauc-8-en-4β-ol, plus five known sesquiterpene compounds, *trans*-dauca-8,11-diene, dauca-5,8-diene, acora-4,9-diene, acora-4,10-diene, (*E*)-β-10,11-dihydro-10, 11-epoxyfarnesene and (*E*)-methylisoeugenol, was isolated and characterised from carrot seed oil (Mazzoni et al.1999). Carrot seed oil was found to be the source of the carotane sesquiterpenes carotol, daucol and β-caryophyllene (Jasicka-Misiak et al. 2004).

Soluble beta-fructofuranosidase with an intracellular location and an isoelectric point of 3.8 (isoenzyme I) was purified and characterised from dry carrot seeds and seedlings (Unger et al. 1992). The purified protein, which was N-glycosylated with high-mannose-containing and high-xylose-containing complex glycans, was eluted as a monomeric polypeptide with a molecular mass of 68,000. The enzyme hydrolyzed sucrose with a Km of 5 mM and a broad pH optimum around 5.0. Carboxylesterase activity was detected in carrot seed and seedling (Melati et al. 1996).

The major oleosin proteins of 15 and 19 kDa and the major storage albumins of 20 and 28 kDa were purified to homogeneity from carrot seeds (Ross and Murphy 1993). Similar-sized proteins in total protein and oil body fractions were observed from non-embryogenic and embryogenic carrot suspension cultures and from carrot somatic embryos. The carrot cultures in-vitro did not accumulate the high levels of octadecenoic fatty acids found in seeds but rather accumulated an oil which was high in linoleic acid and whose fatty acid profile resembled that of the membrane lipids. Non-embryogenic carrot cell cultures accumulated very little starch, whereas high levels were found in embryogenic cell cultures. Starch levels declined to low levels during somatic embryo development to the torpedo stage. In the early stage of carrot seed development, triacylglycerols comprised approximately 43 % of linoleic acid and almost equal proportions of myristic, palmitic, petroselinic, oleic and linolenic acids (Dutta and Appelqvist 1991). Petroselinic acid content increased rapidly up to about 3 weeks after pollination and levelling to approximately 75 %. Linoleic acid was the major component in total polar lipids at both early and mature seed stage, approximately 39 % and 32 %, respectively. Linolenic acid decreased from about 27 % at early to about 3 % at mature stage with concomitant increase in oleic and petroselinic acids. In roots, both triacylglycerols and total polar lipids had linoleic acid as the major fatty acid, 75 % and 69 %, respectively. No petroselinic acid was found in leaves before flowering. However, a very small amount of petroselinic acid was found besides the predominant linoleic and linolenic acids in the triacylglycerol fraction in leaf lipids of plants carrying maturing seed. Seed coats had 45 % petroselinic acid in triacylglycerol but only 1.8 % in total polar lipids. Somatic embryos initiated from developing seeds of domestic carrot failed to accumulate any detectable amount of petroselinic acid in the lipids. Carrot seed was found to contain crotonic acid (*E*)-2-butenoic acid (Jasicka-Misiak et al. 2005).

Storage proteins were isolated from dry carrot achenes (Dodeman et al. 1998). These proteins consisted of glycoproteins, the most abundant of which displayed a molecular mass (M(r)) of 58,000, albumins of M(r) 42,000 comprising at least one beta-1,3-glucanase and two globulins of M(r) 90,000 and 50,000–55,000 respectively, the second being an oligomer composed of three subunits of M(r) 13,000, 20,000 and 30,000. None of these storage proteins identified in the endosperm were detected in zygotic embryos. In contrast, two novel proteins were isolated from zygotic embryos, namely, a globulin family of M(r) 50,000 and pI 6.3–6.8, which was named 'daucin', and a late embryogenesis abundant (LEA) protein family of M(r) 25,000 named 'RAB25'. Since the latter proteins were apparently absent

in the endosperm, the results suggested that the maturation of carrot zygotic embryos required its own specific set of storage and LEA proteins.

Leaf/Stem Phytochemicals

The following flavonoids were isolated from carrot leaves: luteolin 7-β-D-glucoside, luteolin 4′-β-D-glucoside, luteolin 7-β-D-glucuronide, apigenin 7-β-D-glucoside, apigenin 7-rutinoside, chrysoeriol 7-β-D-glucoside and luteolin 7-rutinoside (Teubert et al. 1977). In *Daucus carota* leaf, the 7-and 4′-sulfates of luteolin were found; the two characters were polymorphic and appeared to be present more frequently in north temperate than in south temperate populations (Harborne and King 1976). In carrot leaf and root tissues, monoterpenes were biosynthesised exclusively via the 1-deoxy-D-xylulose/2-C-methyl-D-erythritol-4-phosphate (DOXP/MEP) pathway, whereas sesquiterpenes were generated by the classical mevalonic acid pathway as well as by the DOXP/MEP route (Hampel et al. 2005). The experiments demonstrated independent de novo biosynthesis of terpenoids in carrot roots and in carrot leaves. Flavonoid (chlorogenic acid (CA), luteolin 7-*O*-(6″-*O*-malonyl)-β-D-glucopyranoside (L7MG) and luteolin 7-glucoside (L7G)) concentrations were highest in the tissues of new alternate leaves of the reproductive shoot or in new carrot spring foliage (Brooks and Feeny 2004). Chlorogenic acid concentrations in leaf tissues increased throughout the growing season. Leaf-surface amounts of CA, L7G and L7MG were highest at the point in the life cycle when plants were differentiating or bolting.

Constituents identified in carrot leaf and stem essential oil included: caryophyllene (17.24 %), (+)-*epi*-bicyclosesquiphellandrene (10.14 %), phytol (6.35 %), (1*R*)-α pinene (5.69 %), D-limonene (4.98 %), 3, 7-dimethyl-1, 3, 7-octatriene (4.85 %), 1-methyl-4-(1-methylethylidene)-cyclohexene (3.65 %), 3, 7-dimethyl-(*Z*)-1, 3, 6-octatriene (3.25 %), 1, 1, 4, 8-tetramethyl-*cis*, *cis*, *cis*-4, 7, 10-cycloundecatriene (2.47 %), 1-methyl-4-(1-methylethyl) -1, 4-cyclohexadiene (1.81 %), 1,2,4-trimethoxy-5-(1-propenyl)-(*Z*)-benzene (1.67 %), hexacosane (1.20 %), caryophyllene oxide (1.09 %), camphene (0.43 %), 4-methyl-1-(1-methylethyl)-bicyclo[3. 1. 0] hex-2-ene (0.19 %), β-pinene (0.53 %), β-myrcene (0.53 %), 1-methyl-3-(1 -methylethyl)-benzene (0.47 %), 4-methyl-1-(1-methylethyl) -(*R*)-3-cyclohexen-1-ol (0.10 %), α,α, 4-trimethyl-3-cyclohexene-1-methanol (0.11 %), acetic acid, 1, 7, 7-trimethyl-bicyclo[2. 2. 1] hept-2-yl ester (0.24 %), 2, 5, 5-trimethylcyclohex-2-enone (0.12 %), 1-(2-butenyl) -2, 3-dimethyl-benzene (0.1 %), 4-ethenyl-4-methyl-3-(1-methylethenyl) -1-(1-methylethyl) -(3*R*-*trans*) -cyclohexene (0.47 %), 1-(2, 6, 6-trimethyl-1, 3-cyclohexadien-1-yl) -2-buten-1-one (0.20 %), 4-methyl-8-quinolinol (0.24 %), copaene (0.36 %), 1a, 2, 3, 5, 6, 7, 7 a, 7b-octahydro-1, 1, 7, 7a-tetramethyl-[1a*R* -(1aα, 7α,7aα, 7bα)] -1H -cyclopropa[a] naphthalene (0.88 %), 1-methyl-2-(1-methylethyl)-benzene (0.20 %), octahydro-7-methyl-3-methylene-4-(1-methylethyl) -, [3a*S* -(3aα, 3bβ,4β, 7α, 7 a*S**)] -1H-cyclopenta[1, 3] cyclopropa[1, 2] benzene (0.28 %), 7, 11-dimethyl-3-methylene-(*Z*) -1, 6, 10-dodecatriene (0.16 %), germacrene D (0.13 %), α-farnesene (0.92 %), γ-elemene (0.63 %), 1-methyl-4-(5-methyl-1-methylene-4-hexenyl)-(*S*)-cyclohexene (1.26 %), 2, 3, 4, 7, 8, 8a-hexahydro-3, 6, 8, 8-tetramethyl-[3*R*-(3α, 3aβ, 7β,8aα)] -1H -3a, 7-methanoazulene (0.21 %), 1, 2, 3, 4, 4a, 5, 6, 8 a-octahydro-7-methyl-4-methylene-1-(1-methylethyl) -(1α, 4aβ, 8aα)-naphthalene (0.09 %), 1, 2, 3, 5, 6, 8a-hexahydro-4,7-dimethyl-1-(1-methylethyl)-(1*S*-*cis*)-naphthalene (0.46 %), 1, 3-*bis*(1-methylethyl) -1, 3-cyclopentadiene (0.38 %), 4-methylene-1-methyl-2-(2-methyl-1-propen-1-yl) -1-vinyl-cycloheptane (0.06 %), epizonarene (0.20 %) τ-muurolol (0.56 %), α-cadinol (0.77 %), 1-methyl-6-methylenebicyclo[3. 2. 0]heptane (0.13 %), α-bisabolol (1.66 %), 1-{2-[3-methyl-3-(5-methyl-furan-2-yl) -butyl] –oxiran-2-yl}-ethanone (0.12 %), 9-octadecyne (0.63 %), N -(3, 4-dichlorophenyl) -2-methyl-2-propenamide (0.42 %), 2, 6, 11, 15-tetramethyl-hexadeca-2, 6, 8, 10 %), geranyl tiglate (0.14 %), 1, 2, 3, 4-tetrahydro-5, 7-dimethyl-naphthalene (0.14 %), hexadecahydro-fluoranthene (0.18 %), 1-(2-butenyl)-

2, 3-dimethyl-benzene (0.42 %), 1-(1-naphthyl) ethanol (0.12 %), docosane (0.11 %), 1-cyclohexyl-3-methyl-butane-1, 1-dicarbonitrile (0.41 %), tricosane (0.21 %), 3, 3, 6-trimethyl-1, 5-heptadien-4-one (0.42 %), tetracosane (0.28 %), pentacosane (0.12 %), heptacosane (0.11 %) and nonacosane (0.80 %) (Wu et al. 2006).

Two furocoumarins, 8-methoxypsoralen and 5-methoxypsoralen, were detected in all parts of fresh carrot plants (Ceska et al. 1985) including fruits (Ceska et al. 1986). Carbonic anhydrases were purified and characterised from leaves and roots of mature *Daucus carota* cv. nantes (Demir et al. 1997). Each enzyme molecule was a hexamer having M_r 137,800 and the subunit M_r was 22,800. A dimer carbonic anhydrase with M_r of 45,700 was also detected. The amount of this dimer was higher in leaves than in roots.

Antioxidant Activity

The antioxidant activity of processed (blanched and dehydrated) and raw purple carrots as measured by DPPH (1, 1-diphenyl-2-picrylhydrazyl) EC_{50} value ranged from 7.80 to 30.23 mg sample/mg DPPH (Uyan et al. 2004). Studies by Zhang and Hamauzu (2004) suggested that phenolics could play an important role in antioxidant properties in carrots, and other hydroxycinnamic derivatives such as dicaffeoylquinic acids in the extracts may exert some strong antioxidant activities along with chlorogenic acid, the major hydroxycinnamic acid, representing from 42.2 % to 61.8 % of total phenolic compounds detected. The phenolic contents in different tissues decreased in the following order: peel > phloem > xylem. Although carrot peel accounted for only 11.0 % of the amount of the carrot fresh weight, it could provide 54.1 % of the amount of total phenolics in 100 g fresh weight of carrots, while the phloem tissue provides 39.5 %, and the xylem tissue provides only 6.4 %. All phenolic extracts had stronger radical scavenging ability than pure chlorogenic acid, vitamin C and β-carotene.

Ravindra and Narayan (2003) found that the anthocyanin obtained from carrot callus culture exhibited an antioxidation activity stronger than malvidin, peonidin and alpha-tocopherol and weaker than delphinidin at pH 2, 4 and 7 by the linolenic acid auto-oxidation system. Studies by Zhang and Hamauzu (2004) suggested that phenolics could play an important role in the antioxidant properties in carrots, and other hydroxycinnamic derivatives such as dicaffeoylquinic acids in the extracts may exert some strong antioxidant activities along with chlorogenic acid, the major hydroxycinnamic acid, representing from 42.2 to 61.8 % of the total phenolic compounds detected. The phenolic contents in different tissues decreased in the following order: peel > phloem > xylem. Although carrot peel accounted for only 11.0 % of the amount of the carrot fresh weight, it could provide 54.1 % of the amount of total phenolics in 100 g fresh weight of carrots, while the phloem tissue provides 39.5 %, and the xylem tissue provides only 6.4 %. All phenolic extracts had stronger radical scavenging ability than pure chlorogenic acid, vitamin C and β-carotene. Nicolle et al. (2004b) found that the amount of total phenolic acids varied widely in the 20 coloured carrot cultivars, ranging from 3.3 to 16.9 mg of GAE/g of dry weight (gallic acid equivalent). Among fresh material, low levels of phenolics were found in white cultivars (3.3–3.4 mg GAE/g of dry weight), in yellow (4.3–4.4 mg GAE/g dry weight) and in orange cultivars (from 3.3 to 6.0 mg GAE/g dry weight), whereas purple cultivars contained higher amounts of phenolics (9.6 and 16.9 mg GAE/g dry weight). In terms of antioxidant activities against peroxyl radical ($ROO^{\bullet}$)-generated AAPH [2,2′-azo-bis(2-amidinopropane)dihydrochloride sulfate], the dark orange cultivars had the highest ORAC (oxygen radical absorption capacity) values. Most of the orange cultivars had ORAC values that fell in the average (8.9 μmol Trolox equivalent/gram fresh weight), whereas the white cultivars had the lowest ORAC values. No significant difference between yellow, purple and most of the orange lines was observed. The highest content of carotenoids (mg/100 g Fw) was found in orange

cultivars: 'Kazan F_1' 17.1 mg β-carotene, 28 mg carotenes and 1.5 mg xanthophylls; 'Afro F_1' 16.7 mg β-carotene, 27.4 mg carotenes and 1.1 mg xanthophylls; 'Salsa F_1' 13.9 mg β-carotene, 22.8 mg carotenes and 1.3 mg xanthophylls; and 'Korund F_1' 13 mg β-carotene, 19.7 mg carotenes and 1.8 mg xanthophylls (Mech-Nowak et al. 2012). The lowest carotenoids were found in white and yellow cultivars: 'White Satin F_1' 0.1 mg β-carotene, 0.1 mg carotenes and 0.4 mg xanthophylls and 'Yellowstone F_1' 0.5 mg β-carotene, 0.5 mg carotenes and 2.2 mg xanthophylls, while 'Deep Purple F_1' purple rooted with a yellow core had slightly higher carotenoids 0.9 mg β-carotene, 1.3 mg carotenes and 2.2 mg xanthophylls. DPPH antioxidant activity did not correspond with total carotenoid contents with the exception of 'Kazan F_1'. Despite having low-carotenoid content, 'Deep Purple F_1' had highest antioxidant capacity indicating that other compounds tocopherol, unsaturated fatty acids and polyphenols including anthocyanins may be responsible for its antioxidant capacity. No relevant differences were not found in total antioxidant capacity (DPPH) between tested 'Nante', 'Bolero', 'Champion' and 'Maestro' carrot hybrids as 22.33 % DPPH, 22.16 % DPPH and 22.84 % DPPH, respectively, but different antioxidant capacity was detected in carrot hybrids 'Forto' and 'Berlikum', as 24.28 % DPPH and 23.12 % DPPH, respectively (Rakcejeva et al. 2012).

Studies showed that the highest values for quality characteristics, such as antioxidant capacity and total pectin, total phenolic and total carotenoid contents of carrot juice, were obtained with the combined electrical applications (electroplasmolysis + microwave) (Rayman and Baysal 2011). As a result of electroplasmolysis, a 9.7 % increase in juice yield was obtained. In addition, 100 % pectin methylesterase inactivation was found with the microwave heating application. In addition, these quality characteristics were protected better in the group of combined applications of the electrical methods (electroplasmolysis + microwave) during storage. Compared with fresh carrot juice, blanching and enzyme liquefaction could result in the increase of the total polyphenol content (TPC) and the antioxidant activity in scavenging DPPH free radicals (DPPH) and Fe(2+)-chelating capacity (FC), whereas pasteurisation could result in the decrease of the TPC and the antioxidant activity in DPPH and FC (Ma et al. 2013). In contrast, blanching, enzyme liquefaction and pasteurisation showed little influence on the antioxidant activity in lipid peroxidation protection. Polyphenols still retained high antioxidant activity after the processes, with potential health benefits for consumers.

Of the following coloured carrots, orange, white, yellow, red, solid-coloured purple and purple with an orange core, the higher α-carotene content in the orange cultivar and the purple cultivar with an orange core resulted in a higher antioxidative capacity (Grassmann et al. 2007). Also, the lycopene content in the red cultivar was higher in 2004 than in 2003, which again led to an increased antioxidative capacity. In the case of phenolics, higher values were found for the purple-coloured cultivars in 2004, which only in the case of the purple cultivar with an orange core, however, led to a higher antioxidative capacity.

In seven coloured carrots, anthocyanins were the major antioxidants in purple–yellow and purple–orange carrots, and chlorogenic acid was a major antioxidant in all carrots (Sun et al. 2009). Chlorogenic acid, caffeic acid, *p*-hydroxybenzoic acid, ferulic acid and other cinnamic acid isomers predominated in carrots of different colours. Carotenoids did not contribute to total antioxidant capacity, but correlated with antioxidant capacity of hydrophobic extracts. Both the DPPH (2,2′-diphenyl-1-picrylhydrazyl) and ABTS (2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) assays showed that the hydrophilic extract had higher antioxidant capacity than the hydrophobic extract. Purple–yellow carrots had the highest antioxidant capacity, followed by purple–orange carrots, and the other carrots did not significantly differ. The antioxidant capacity of purple–yellow carrots was >90 times higher than that of the hydrophobic extracts in both ABTS and DPPH assays. Purple carrots had higher antioxidant capacity values due to their anthocyanin

content (Metzger and Barnes 2009). Deep Purple carrot had the highest concentration of total polyacetylenes, total α-tocopherol and total phenolics. The reducing capacity expressed in Trolox equivalents units of two black carrot cultivar extracts from Cuevas Bajas, Spain, was determined to be 86.4 and 182.0 μM TE/100 g fw and the radical scavenging ability to be 17.6 and 240.0 μM TE/100 g fw (Algarra et al. 2014). The antioxidant features of the black carrot extracts were shown to be significantly higher than those of orange carrots. Pectinase enzyme-assisted processing significantly improved the antioxidant composition of black carrot juice (Khandare et al. 2011). There was an overall increase of 33 % in juice yield, 27 % in total phenolics and 46 % in total flavonoids. The total anthocyanin content in black carrot juice was almost doubled. The in-vitro total antioxidant activity in black carrot juice extracted through enzyme-assisted processing was 30.0 and 62.0 μmol TE/mL in ferric reducing antioxidant power (FRAP) and cupric-reducing antioxidant capacity (CUPRAC) assays, respectively.

Purple carrot cultivars possessed on average 9 times more phenolics in mg/100 g FW (245.7 mg total phenols (Folin–Ciocalteu), 311.5 mg total phenols (UV/Vis), 95 mg phenylpropanoids, 51.6 mg flavonols) and high in anthocyanins (64.9 mg/100 g FW) than roots of other colours and exhibited the highest radical scavenging activity (RSA) 51.5 % (Leja et al. 2013). Red carrot cultivars contained 31 mg total phenols (Folin–Ciocalteu), 40.4 mg total phenols (UV/Vis), 9.6 mg phenylpropanoids, 6.5 mg flavonols and 0.5 mg anthocyanins and had an RSA of 9.3 %. The orange, white and yellow exhibited lower RSA, on average, at 6 % level. Orange carrot cultivars contained 29.3 mg total phenols (Folin–Ciocalteu), 39.6 mg total phenols (UV/Vis), 9.5 mg phenylpropanoids, 6.5 mg flavonols and 0.5 mg anthocyanins and had an RSA of 6.6 %. Yellow carrot cultivars contained 21.5 mg total phenols (Folin–Ciocalteu), 35.3 mg total phenols (UV/Vis), 9.5 mg phenylpropanoids, 6.5 mg flavonols and 0.5 mg anthocyanins and had an RSA of 6.0 %. White carrot cultivars contained 186 mg total phenols (Folin–Ciocalteu), 24.2 mg total phenols (UV/Vis), 5.4 mg phenylpropanoids, 3.5 mg flavonols and 0.2 mg anthocyanins and had an RSA of 6.0 %. Carrots of Asian origin belonging to Eastern gene pool were more often purple or red and richer in phenolics and had higher antiradical activity than those from the Western gene pool with mainly orange roots.

Intense wounding (23.5 cm^2/g) of carrots induced approximately 2.5- and 12.4-fold increase in soluble phenolics and antioxidant capacity, respectively, after 4 days compared to whole carrots (Surjadinata and Cisneros-Zevallos 2012). Wounding induced the synthesis of mainly chlorogenic acid (5-CQA) and 3,5-dicaffeoylquinic acid. A higher proportion of 5-CQA in the phenolic mixture was responsible for an increasing specific antioxidant capacity (809 and 1,619 μg Trolox/mg phenolics for whole carrots and shreds, respectively, for Choctaw cultivar). Wounded carrots can be promoted as an inexpensive rich source of phenolic antioxidants for the regular diet. Carrot oil (extracted from the umbels) exhibited antioxidant activity in-vitro using 1,1-diphenyl-2-picryl hydrazyl free radical scavenging assay (DPPH), ferrous ion chelating assay (FIC) and the ferric reducing antioxidant power assay (FRAP) (Shebaby et al. 2013). The FRAP value was 164 μmol $FeSO_4/g$, and the IC_{50} values for DPPH and FIC assays were 2.1 mg/ml and 0.43 mg/ml, respectively.

Studies by Chatatikun and Chiabchalard (2013) demonstrated that ethanolic extracts of baby carrot and carrot had a high amount of phenolic and flavonoid compounds and had high antioxidant activities as measured by DPPH and ABTS. Baby carrots had higher antioxidant activities than carrots, and the ethanolic extracts of carrot and baby carrot showed higher antioxidant activities than petroleum extracts. Fractions with high phenolic or flavonoid contents also had high antioxidant activities when they were assayed by DPPH and ABTS.

Ethanolic extracts of baby carrots (33.0 mg VCEAC/g dry plant material) and carrots (27.5 mg VCEAC/g dry plant material) had significantly higher DPPH antioxidant activities as compared to those found in petroleum extracts.

Ethanolic extracts from baby carrots and carrots had antioxidant activities of 42.2 and 34.5 mg VCEAC/g dry plant material, respectively. Ethanolic extracts of baby carrots and carrots showed high scavenging activities with IC_{50} = 830 µg/ml and 837.5 µg/ml, respectively. Antioxidant activities of petroleum extract from baby carrots and carrots were 14.7 and 4.2 mg VCEAC (vitamin C equivalent antioxidant capacity)/g dry plant material, respectively. Ethanolic extracts of baby carrot and carrot had a total phenolic content of 35.9 and 30.7 mg GAE/g dry plant material, respectively. Ethanolic extracts from baby carrots and carrots had total flavonoid contents of 35.3 and 20.4 mg QE/g dry plant material, respectively, while petroleum extracts from baby carrot and carrot had total flavonoid content of 17.7 and 3.7 mg. The results suggested that baby carrots had higher flavonoid contents than carrots and the ethanolic extracts had higher flavonoid contents than the petroleum extracts.

Although the dichloromethane flower extract showed potent DPPH scavenging activity (32.57 %), the isolated compounds D, L-iditol, kaempferol 3-*O*-B-glucoside, laserine and a mixture of stigmasterol and sitosterol showed weaker activity; kaempferol 3-*O*-B-glucoside showed higher 9.2 % activity than the other compounds (Akgul et al. 2009).

Anti-inflammatory Activity

Volatile oil of carrot seeds at 50 and 100 mg/kg resulted in 60 and 70 % inhibition of carrageenan-induced rat paw oedema, respectively (Porchezhian et al. 2000). Carrot seed extract at doses of 200 and 400 mg/kg significantly inhibited carrageenan-, histamine- and serotonin-induced paw oedema as well as formaldehyde-induced arthritis in rats (Vasudevan et al. 2006).

2,4,5-trimethoxybenzaldehyde (1), oleic acid (2), *trans*-asarone (3) and geraniol (4) isolated from carrot seeds were found to be cyclooxygenase inhibitors (Momin et al. 2003). All four compounds exhibited 3.32, 45.32, 46.15 and 3.15 % of prostaglandin H endoperoxide synthase-I (COX-I) inhibitory activity and 52.69, 68.41, 64.39 and 0 % prostaglandin H endoperoxide synthase-II (COX-II) inhibitory activity at 100 mg/ml, respectively. Compound 1 showed selectivity towards COX-II enzyme inhibition at 100 µg/mL. The inhibition of COX-II enzymes by compounds 1 at 100 µg/mL was significant when compared to aspirin, ibuprofen, naproxen and Celebrex at concentrations studied.

A bioactive chromatographic fraction of purple carrot extract attenuated lipopolysaccharide (LPS) inflammatory response (Metzger et al. 2008; Metzger and Barnes 2009). There was a dose-dependent reduction in nitric oxide production and mRNA of proinflammatory cytokines (IL-6, IL-1beta, TNF-alpha) and iNOS in macrophage cells. Protein secretions of IL-6 and TNF-alpha were reduced 77 and 66 % in porcine aortic endothelial cells treated with 6.6 and 13.3 µg/mL of the LH-20 fraction, respectively. Polyacetylene compounds falcarindiol, falcarindiol 3-acetate and falcarinol isolated from the bioactive fraction reduced nitric oxide production in macrophage cells by as much as 65 % without cytotoxicity. The results suggested that polyacetylenes, not anthocyanins, in purple carrots were responsible for anti-inflammatory activity. Only seven coloured carrot varieties had inhibitory activity (IC_{25} = 257–1,321 µg/mL) in macrophage cells. Carrot aqueous extract exhibited anti-inflammatory effect on acetic acid-induced experimental colitis in rats (Patil et al. 2012a). Seven days pretreatment with carrot aqueous extract (200 and 400 mg/kg, p.o.) significantly decreased stool consistency, macroscopic score and colitis-elevated colon weight, colon width, colon weight to length ratio, spleen weight, ulcer area, ulcer index, colonic myeloperoxidase and nitric oxide. Carrot extract significantly attenuated histological alterations associated with acetic acid-induced ulcerative colitis.

Cardiovascular Protective Activity

Administration of carrot extract ameliorated the adverse effects of isoproterenol-induced myocardial infarction in rats and maintained cardiac

tonicity (Muralidharan et al. 2008). Isoproterenol-elevated serum aspartate transaminase and alanine transaminase, lactate dehydrogenase, lipid peroxidase levels and elevated lipid peroxidation in heart homogenate were decreased by carrot extract. The decreased total protein and lactate dehydrogenase levels in the heart homogenate were restored to near normal levels by carrot extract. The levels of Na^+K^+ATPase and Mg^{2+}ATPase were decreased and that of Ca^{2+}ATPase was increased in carrot-treated group significantly. Potter et al. (2011) found that adults drinking carrot juice may protect the cardiovascular system by increasing total antioxidant status and by decreasing lipid peroxidation independent of any of the cardiovascular risk markers measured. Drinking carrot juice did not affect the plasma cholesterol, triglycerides, Apo A, Apo B, LDL, HDL, body fat percentage, insulin, leptin, interleukin-1a or C-reactive protein. Drinking carrot juice decreased systolic pressure, but did not influence diastolic pressure. Drinking carrot juice significantly increased the plasma total antioxidant capacity and decreased plasma malondialdehyde production.

Hepatoprotective Activity

Carrot extract exhibited hepatopreotective activity against carbon tetrachloride (CCl_4)-induced hepatocellular injury in mice (Bishayee et al. 1995). The elevated serum enzyme levels (viz., serum glutamate oxaloacetate transaminase (SGOT), serum glutamate pyruvate transaminase (SGPT), lactate dehydrogenase, alkaline phosphatase (ALP), sorbitol and glutamate dehydrogenase) by CCl_4 induction were significantly lowered due to pretreatment with carrot extract. The extract also decreased the elevated serum bilirubin and urea content due to CCl_4 administration. Increased activities of hepatic 5′-nucleotidase, acid phosphatase, acid ribonuclease and decreased levels of succinic dehydrogenase, glucose 6-phosphatase and cytochrome P450 produced by CCl_4 were reversed by the extract in a dose-responsive manner. On another study, oral administration of carrot extract (25 mL/kg/day) for 30 days produced significant hepatoprotection against lindane (20 mg/kg/day)-induced hepatotoxicity in rats (Balasubramaniam et al. 1998). The elevated levels of serum enzymes, namely, aspartate transaminase, alanine transaminase and alkaline phosphatase and the levels of thiobarbituric acid reactive substances, cholesterol, triglycerides and LDL cholesterol in lindane administered rats were observed to be decreased significantly in the lindane + carrot extract group. The carrot extract also restored the depressed antioxidants and HDL cholesterol levels to near normal. Singh et al. (2012b) reported that methanol carrot seed extract protected the liver against oxidative stress induced in rats by thioacetamide. Carrot seed-treated rats showed a significant decrease in SGPT, SGOT and ALP levels and lipid peroxidation compared to the thioacetamide group. Carrot seed extract-treated group recorded increases in antioxidant enzymes, superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GRD), glutathione peroxidase (GPX) and glutathione S-transferase (GST).

Gastroprotective Activity

Administration of carrot juice at the dose of 200 and 400 mg/kg to rats significantly decreased gastric volume, free acidity, total acidity and ulcer index, while it increased the pH and the mucus content as compared with control (Nayeem et al. 2010). Carrot juice at a dose of 400 mg/kg produced 60.45, 56.80 and 43.51 % significant inhibition when gastric ulceration were induced by pylorus ligation, aspirin and ethanol, respectively. The results indicated that carrot juice possessed gastroprotective property and the results supported traditional uses of the roots of this plant in the treatment of gastric ulcer and acidity.

Anticancer Activity

In-Vitro Studies

Among all the compounds isolated from carrot roots, phloretin and quercetin were the most

effective in decreasing the viability of human colon cancer cell lines (HT29 and LoVo cells) (Przybylska et al. 2007). In the case of HT29 cells, the IC_{50} for phloretin was determined as 400 µmol/L and 260 µmol/L after 5 hour and 24 hour incubation, respectively, whereas for LoVo cells the IC_{50} was determined as 380 µmol/L and 170 µmol/L after 5 hour and 24 hour incubation, respectively. The addition of chlorogenic acid (present in both carrot juice and roots) and caffeic acid (present in carrot juice) to the cell culture medium reduced the viability of both cell lines in a significant manner. Caffeic acid was significantly more effective, decreasing survival of HT29 cells to 62.06 % and 25.07 % at 500 µmol/L and 1,000 µmol/L, respectively. LoVo cells were less sensitive to caffeic acid, the highest concentration (1,000 µmol/L) decreasing viability to 68.27 % after 24 hours. Chlorogenic acid had less effect on the viability of both cancer cell lines. A nonpolar active phenylpropanoid component from carrot, 2-epilaserine, exhibited significant cytotoxicity against HL-60 cancer cells (Yang et al. 2008). Carrot oil (extracted from the umbels) exhibited anticancer activity against human colon (HT-29, Caco-2) and breast (MCF-7, MDA-MB-231) cancer cell lines (Shebaby et al. 2013). It exerted a significant increase in cell death and decrease in cell proliferation in a time- and dose-dependent manner.

The sesquiterpene daucucarotol, isolated from the fruit, displayed weak cytotoxic activity against human gastric cancer cell lines BGC-823 with inhibition of 13.3 %, but showed less cytotoxicity against AGS (Fu et al. 2009). Daucuside (1) and daucusol (2) were isolated from the fruits and were also evaluated for the cytotoxic effects against two human gastric cancer cell lines BGC-823 and AGS (Fu et al. 2010c). Treatment of leukaemia cell lines with carrot juice extract induced apoptosis and inhibited progression through the cell cycle (Zaini et al. 2011). Lymphoid cell lines were affected to a greater extent than were myeloid cell lines, and normal haematopoietic stem cells were less sensitive than most cell lines. The study showed that extracts from carrots could induce apoptosis and cause cell cycle arrest in leukaemia cell lines. Carrots had been reported to contain beneficial agents, such as β-carotene and polyacetylenes, which could be effective in the treatment of leukaemia.

A hormesis effect was seen for isolated carrot polyacetylenes (falcarinol and falcarindiol) when added to Caco-2 cancer cells in concentrations ranging from 1 ng/mL to 20 µg/mL (Purup et al. 2009). The relative inhibitory potency was falcarinol > falcarindiol. No hormesis effect was observed when adding the polyacetylenes to human intestinal epithelial cells of normal origin (FHs 74 Int.). Combinations of falcarinol and falcarindiol added to normal and cancer cells showed a synergistic response for the inhibition of cell growth. Extracts of carrots, containing different amounts of falcarinol, falcarindiol and falcarindiol 3-acetate had significant inhibitory effects on both normal and cancer cell proliferation. In cancer cells, the extract containing the highest concentration of falcarinol tended to have the highest growth inhibitory effect, in accordance with a higher potency of falcarinol than falcarindiol. In another study, treatment of all three human lymphoid leukaemia cell lines with the fraction from carrot extracts which contained polyacetylenes (falcarinol, falcarindiol and falcarindiol 3-acetate) and carotenoids (β-carotene and lutein) was significantly more cytotoxic than the four other fractions (Zaini et al. 2012). Treatments with purified polyacetylenes also induced apoptosis in a dose- and time-responsive manner. Moreover, falcarinol and falcarindiol 3-acetate isolated from carrot were more cytotoxic than falcarindiol. In contrast, the carotenoids showed no significant effect on either apoptosis or cell proliferation in any of the cells investigated. Ethanol extracts of lyophilised black carrot calli and black carrot harvested from fields were assayed for anticancer activity in-vitro on various human cancer cell lines including MCF-7, SK-BR-3 and MDA-MB-231 (human breast adenocarcinomas); HT-29 (human colon adenocarcinoma); PC-3 (human prostate adenocarcinoma); and Neuro-2A (*Mus musculus* neuroblastoma) cancer cell lines (Sevimli-Gur et al. 2013). The highest cytotoxic activity was achieved against Neuro-2A cell lines exhibiting viability of 38–46 % at 6.25 µg/ml concentration

for all calli and natural extracts. A significantly high IC_{50} value of 170.13 μg/ml was attained in normal cell line Vero indicating that its potential as an ideal candidate for the treatment of brain cancer without causing negative effects to normal healthy cells.

Animal Studies

The petroleum ether extract of carrot seeds administered intraperitoneally at doses of 3 mg and 10 mg/kg body weight/day for 7 days showed antitumour activity, inhibiting the growth of Ehrlich ascites tumour in mice (Majumder and Gupta 1998). Kobaek-Larsen et al. (2005) found that the dietary treatments of a standard rat feed Altromin supplemented with either carrot containing 35 μg/g falcarinol or maize starch supplemented with 35 μg falcarinol/g purified from carrots delayed or retarded the development of large aberrant crypt foci and azoxymethane (AOM)-induced colon preneoplastic tumours in male BDIX rats. Zeinab et al. (2011) reported that topical treatment of carrot umbel oil extract exhibited remarkable antitumour activity against 7,12-dimethyl benz(a)anthracene (DMBA)-induced skin cancer compared with non-treated mice. Carrot oil delayed tumour appearance and inhibited tumour incidence and yield.

Survey/Clinical Studies

In a food and supplement use in a population-based case-control study of breast cancer risk conducted in Maine, Massachusetts, New Hampshire and Wisconsin in 1988–1991, Longnecker et al. (1997) found that eating carrots or spinach more than twice weekly, compared with no intake, was associated with an odds ratio of 0.56 (95 % confidence interval 0.34–0.91). Estimated intake of preformed vitamin A from all evaluated foods and supplements showed no trend or monotonic decrease in risk across categories of intake. These data did not allow them to distinguish among several potential explanations for the protective association observed between intake of carrots and spinach and risk of breast cancer. The findings were, however, consistent with a diet rich in these foods having a modest protective effect. In a randomised crossover trial of 22 healthy young men on a low-carotenoid diet, consumption of carrot juice led to a marked increase of β-carotene and α-carotene in faeces and faecal water, as did lycopene after consumption of tomato juice (Schnäbele et al. 2008). Faecal water showed high dose-dependent cytotoxic and antiproliferative effects on colon adenocarcinoma cells (HT29). These effects were not markedly changed by carrot and tomato juice consumption. Neither bile acid concentrations nor activities of the bacterial enzymes beta-glucosidase and beta-glucuronidase in faecal water changed after carrot and tomato juice consumption. Faecal water pH decreased only after carrot juice consumption. Short-chain fatty acids (SCFA) were probably not responsible for this effect, as SCFA concentrations and profiles did not change significantly. In summary, the 2-week intervention with carotenoid-rich juices led only to minor changes in investigated luminal biomarkers relevant to colon carcinogenesis. Based on evidence that higher plasma carotenoid concentrations may be protective in relation to breast cancer recurrence, Butalla et al. (2012) conducted a study on carrot juice intervention of 69 overweight breast cancer survivors. They found daily intake of fresh carrot juice to be a simple and effective approach to increasing plasma total carotenoids and in turn reducing oxidative stress, but not inflammatory markers, in women previously treated for breast cancer.

Antihypercholesterolemic Activity

A 3-week diet supplementation with carrot (15 % dry matter) caused a significant decrease of liver cholesterol and liver triglycerides in cholesterol-fed rats (Nicolle et al. 2003). Faecal total steroid excretion increased by 30 % upon feeding the carrot diet as compared to the control. The secretion of bile acids was maintained, whereas the cholesterol apparent absorption was reduced in rats fed with carrot diet. Carrot consumption also improved the antioxidant status. It significantly decreased the urinary excretion of thiobarbituric acid reactive substances (TBARS), reduced the TBARS levels in heart, increased the

vitamin E plasmatic level and tended to increase the ferric reducing ability of plasma (FRAP) as compared to the controls. The carrot diet provided carotenoid antioxidants: 5.1 mg β-carotene, 1.6 mg α-carotene and 0.25 mg lutein per 100 g diet. β-carotene was also detected in the liver and heart. They also found that although vitamin E was not affected by carrot diet, vitamin E–triglycerides ratio was significantly higher in animals fed with carrot diets. The carrot diet induced an increase of vitamin E in the heart in both cholesterol-free and cholesterol-supplemented mice suggesting a higher protection of this tissue (Nicolle et al. 2004a).

In a randomised, double-blind, placebo-controlled trial of 16 obese males, A 4-week intervention of dried purple carrot (118.5 mg/day of anthocyanins and 259.2 mg/day of phenolic acids) resulted in no statistically significant changes in body mass, body composition, appetite, dietary intake, low density lipoprotein, total cholesterol, blood pressure or C-reactive protein in these obese participants (Wright et al. 2013). However, high density lipoprotein cholesterol was lower in the intervention group. Aspartate aminotransferase and alanine aminotransferase did not change, indicating that the intervention was safe.

Antithrombotic Activity

The different carrot varieties demonstrated a variable effect on thrombosis in-vitro and in-vivo (Yamamoto et al. 2008). In particular, a variety designated SAKATA-0421 exerted an antithrombotic effect in-vivo independent from heat treatment of the filtrate at 100 °C for 10 minutes. After oral intake, the particular heat-resistant variety (SAKATA-0421) showed antithrombotic effect in-vivo possibly due to antiplatelet reactivity and/or spontaneous thrombolytic activity. There was no significant correlation between antithrombotic activity and the levels of polyphenolics and any other biochemical parameter, including antioxidant activity, α-carotene and β-carotene, alpha-tocopherol and ascorbic acid.

Hypotensive Activity

Intravenous administration of two coumarin glycosides coded as DC-2 and DC-3 from carrot caused a dose-dependent (1–10 mg/kg) fall in arterial blood pressure in normotensive anaesthetised rats (Gilani et al. 2000). In in-vitro studies, both compounds caused a dose-dependent (10–200 μg/ml) inhibitory effect on spontaneously beating guinea pig atria as well as on the K^+-induced contractions of rabbit aorta at similar concentrations. These results indicated that DC-2 and DC-3 may be acting through a blockade of calcium channels, and this effect may be responsible for the blood pressure-lowering effect of the compounds observed in the in-vivo studies.

Wound Healing Activity

Animals treated with topical ethanolic extract of *Daucus carota* cream formulation (1 %, 2 % and 4 % w/w) showed significant decrease in wound area, epithelisation period and scar width, whereas rate of wound contraction significantly increased as compared to control group animals in excision wound model (Patil et al. 2012b). In incision wound model there was significant increase in tensile strength, hydroxyproline content and protein content of animals treated with topical carrot root cream formulation (2 % and 4 % w/w, respectively). When applied topically, the cream did not show any sign and symptoms of skin irritation.

Cognitive Function Enhancement Activity

A quaternary base chloride, isolated from a water-soluble fraction of an alcoholic extract of carrot seeds, exhibited procholinergic activity (Gambhir et al. 1966a, b). It was found to inhibit brain cholinesterase activity thereby elevating the brain acetylcholine levels via increased synthesis of acetylcholine, which would in turn prove beneficial in cognitive dysfunctions. Ethanol carrot seed extract (200, 400 mg/kg, p.o.) exerted significant

improvement in memory scores of young mice in the elevated plus maze test and aged mice using the passive avoidance apparatus (Vasudevan and Parle 2006). Further, carrot seed extract reversed the amnesia induced by diazepam. The extract (200, 400 mg/kg, p.o.) reduced significantly the brain acetylcholinesterase activity and cholesterol levels in young and aged mice. The results indicated that carrot seed extract may prove to be a useful remedy for the management of cognitive dysfunctions on account of its multifarious beneficial effects such as memory-improving property, cholesterol-lowering property and anticholinesterase activity. In another study, administration of carrot seed ethanol extract (200 and 400 mg/kg, p.o.) elicited significant improvement in memory of young and aged rats in the elevated plus maze, Hebb-Williams maze and hexagonal swimming pool tests (Mani et al. 2010). Carrot seed extract also reversed the amnesia induced by scopolamine (0.4 mg/kg, i.p.) and diazepam (1 mg/kg, i.p.).

Anticataract/Anti-macular Degenerative Activity

In normotensive rabbits topical application of carrot seed extract at the concentration of 0.3, 0.6 and 1.2 % resulted in mean IOP (intraocular pressure) reduction of 19.33, 23.20 and 25.61 %, respectively, from baseline (Agarwal et al. 2008). In water-loaded rabbits, maximum mean IOP reduction with 0.6 % carrot extract was 29.39 %, which was comparable to pilocarpine. In steroid pretreated rabbits, maximum mean IOP reduction was 30.27 % from baseline, which was significantly higher than pilocarpine. A human intervention study showed that consumption of carrot juice containing high concentrations of the provitamin A carotenoid β-carotene resulted in slightly, non-significantly increased plasma retinol concentrations and significantly increased (almost double, from 1.2 to 2.0 ng/mL) plasma concentrations of all-*trans*-retinoic acid (Rühl et al. 2008). In contrast, consumption of tomato juice and spinach powder resulted in no significant alteration in concentrations of plasma retinol and vitamin A metabolite and all-*trans*-retinoic acid. Yoon et al. (2013) found that pretreatment with extract of carotenoid-overexpressing transgenic carrot enhanced antioxidant and protective activities on degenerative diseases of the eye. The carrot extract reduced cell death in a retinal ganglion cell line, RGC-5 cells, exposed to 1-buthionine-(*R*,*S*)-sulfoximine and L-glutamic acid.

In a randomised, blinded, 3×3 crossover intervention study of four women and five men aged 23–28 years, consumption of yellow carrots rich in lutein significantly increased serum lutein concentrations and did not result in the decrease in β-carotene concentrations that accompanies administration of lutein supplements (Molldrem et al. 2004). Lutein from the yellow carrot treatment was 65 % as bioavailable as that from the lutein supplement treatment. Increasing lutein intake from foods could increase the density of macular pigment of the human retina and decrease the risk of developing macular degeneration.

Antinociceptive Activity

Carrot seed extract at doses of 200 and 400 mg/kg significantly attenuated the writhing responses induced by an intraperitoneal injection of acetic acid and late phase of pain response induced by a subplantar injection of formalin in mice (Vasudevan et al. 2006).

Immunomodulatory Activity

In a blinded, randomised, crossover study of healthy men, supplementation of a low-carotenoid diet with tomato or carrot resulted in relatively fast responses in plasma carotenoid concentrations which were not accompanied by concomitant changes in immune functions (Watzl et al. 2003). For IL-2, NK cell cytotoxicity and lymphocyte proliferation, maximum responses were observed during depletion periods. The highest production rate was measured only for TNF-alpha at the end of the first intervention period.

Juice intervention did not modulate the secretion of IL-4. The study showed that increased plasma carotenoid concentrations after vegetable juice consumption were accompanied by a time-delayed modulation of immune functions in healthy men consuming a low-carotenoid diet.

Zhang et al. (2010) transformed the gene of UreB (urease B) an effective and common immunogen of all strains of *Helicobacter pylori* into carrot by *Agrobacterium*-mediated transformation, and the regenerated carrot plants demonstrated that the expressed UreB protein accounted for 25 μg/g roots was effective to induce immune response in mice. The results suggested that the UreB transgenic carrot could be potentially used as an edible vaccine for controlling *H. pylori*.

Spasmolytic Activity

The tertiary base isolated from carrot seeds was found to have papaverine-like nonspecific smooth muscle relaxant and spasmolytic activity, but its activity was found to be about one tenth of that of papaverine (Gambhir et al. 1979).

Renoprotective Activity

Oral daily administration 14 days prior and 14 days after the induction of renal ischaemia/(I/R) in rats with petroleum ether carrot extract, fractional methanol carrot extract and direct methanol carrot all at 250 and 500 mg/kg dosage significantly reduced the levels of serum creatinine, uric acid and urea compared to disease control (Afzal et al. 2013). The findings demonstrated that postconditioning with carrot root extract significantly improved kidney function in I/R rats.

Vitamin A/Carotenoid/Anthocyanin Availability Activity

Studies showed that a 4-week supplemental feeding with twice the amount of α-carotene isolated from carrots was as effective as β-carotene in maintaining the vitamin A status of Mongolian gerbils (*Meriones unguiculatus*) (Tanumihardjo and Howe 2005). Conversion factors were approximately 5.5 μg α-carotene or approximately 2.8 μg β-carotene to 1 μg retinol. Feeding studies in Mongolian gerbils (*Meriones unguiculatus*) showed that red carrot maintained vitamin A status, but constituent β-carotene may interfere with hepatic lycopene bioavailability (Mills et al. 2007). Another study found that liver stores of β-carotene or vitamin A in the gerbils did not differ between orange and purple carrot diets when equal amounts of β-carotene from each of the diets were consumed (Dosti et al. 2006). Both the orange and purple carrot diet resulted in higher liver vitamin A compared with the supplement. High β-carotene carrots resulted in more than twofold higher β-carotene and 1.1 times greater vitamin A liver stores compared with typical orange carrots. The results suggested that high β-carotene carrots may be an alternative source of vitamin A to typical carrots in areas of vitamin A deficiency. Second, phenolics including anthocyanins and phenolic acids in purple carrot do not interfere with the bioavailability of β-carotene from purple carrots.

In a study of eight healthy females aged 23–36 years old, daily consumption of processed carrots and spinach over a 4-week period produced an increase in plasma β-carotene concentration that averaged three times that associated with the consumption of the same amount of β-carotene from these vegetables in the raw form (Rock et al. 1998). The results suggested that isomerisation of β-carotene by heat treatment did not negate the enhanced β-carotene uptake associated with consuming commercially processed vegetables compared with raw vegetables. The results of two crossover studies in humans showed lycopene and β-carotene to be bioavailable from red carrots, and lycopene absorption appeared to be affected by carrot fibre (Horvitz et al. 2004). It was found that the lycopene in the red carrot was about 44 % as bioavailable as that from tomato paste. Red carrots provide an alternative to tomato paste as a good dietary source of lycopene and also provide bioavailable β-carotene. Administration of orange carrot (OC) and purple carrot (PC) smoothies to female

subjects at breakfast did not affect the absorption of β-carotene postprandially (first 24 hours) (Arscott et al. 2010). Peak plasma concentrations of OC and PC treatments did not differ.

In a clinical feeding study using purple carrots as the anthocyanin source, plasma and urine responses were found to be lower for acylated versus nonacylated anthocyanins from raw carrots (463 μmol of anthocyanins: 400 μmol acylated, 63 μmol nonacylated), 250 g cooked (357 μmol of anthocyanins: 308.5 μmol acylated, 48.5 μmol nonacylated) and 500 g cooked (714 μmol of anthocyanins: 617 μomol acylated, 97 μmol nonacylated) purple carrots (Kurilich et al. 2005). Four of the five carrot anthocyanins were found intact in plasma by 30 minutes after carrot consumption and peaked between 1.5 and 2.5 hours. Acylation of anthocyanins resulted in an 11–14-fold decrease in anthocyanin recovery in urine and an eight to tenfold decrease in anthocyanin recovery in plasma. Cooking increased the recovery of nonacylated anthocyanins but not acylated anthocyanins.

Antimicrobial Activity

Sesquiterpenes daucane esters, 2α-acetyloxy-4β-hydroxy-6α-*p*-hydroxybenzoyloxy-dauc-8-ene, 2α-acetyloxy-4β-hydroxy-6α-angeloyloxy-10β-hydroxybenzoyloxy-dauc-8-ene and fercomin, and ferulenol, from wild carrot roots, exhibited low antibacterial activities against 4 Gram-positive (*Staphylococcus aureus*, *Streptomyces scabies*, *Bacillus subtilis*, *Bacillus cereus*) and two Gram-negative species (*Pseudomonas aeruginosa*, *Escherichia coli*) as well as antifungal against *Fusarium oxysporum* and *Aspergillus niger* (Ahmed et al. 2005). The essential oil obtained from carrot aerial parts at the end of the flowering stage inhibited in-vitro growth of human enteropathogen *Campylobacter jejuni*, *Campylobacter coli* and *Campylobacter lari* strains tested, including one multidrug-resistant *C. jejuni* strain (Rossi et al. 2007). Compounds that were responsible for the antibacterial activity were identified as (*E*)-methylisoeugenol and elemicin.

The strongest antifungal activity was observed for the main constituent of carrot seed oil, carotol, which inhibited the radial growth of *Alternaria alternata* (Jasicka-Misiak et al. 2004). Supercritical extracts contain lower amounts of monoterpenes and higher amounts of sesquiterpene hydrocarbons. Antifungal activities of the Sardinian carrot umbel oils were the highest, particularly for dermatophytes and *Cryptococcus neoformans*, with MIC values of 0.16–0.64 μL/mL (Maxia et al. 2009). Carrot essential oils exhibited antimicrobial activity against *Escherichia coli*, *Staphylococcus aureus* and clinical strains of *Candida albicans* and *C. tropicalis* 1011 RM; the MIC values obtained were all >2.5 % (v/v) (Marzouki et al. 2010). Tunisian carrot seed essential oils exhibited interesting antibacterial and antifungal activities against one Gram-positive (*Staphylococcus aureus*) and two Gram-negative bacteria (*Escherichia coli* and *Salmonella typhimurium*), as well as against a pathogenic yeast (*Candida albicans*) (Rokbeni et al. 2013).

Agglutinating Activity

An extract of *D. carota* induced agglutination of most serotypes of *Streptococcus mutans* but not of *Streptococcus salivarius* or *Streptococcus mitis* (Bratthall 1978). When added to a suspension of mixed bacteria, a piece of *D. carota* may selectively sorb *S. mutans*, while *S. salivarius* and *S. mitis* were affected to a minor degree.

Carrot cell cultures were found to secrete a lectin, with the molecular weight of 58,000, which could strongly enhance the activation of carrot prophenoloxidase by $CaCl_2$ (Söderhäll et al. 1990). The purified protein did also show haemagglutinating activity towards rat as well as rabbit erythrocytes, and this activity was inhibited by N-acetylglucosamine or fetuin.

Analgesic Activity

Writhing induced by acetic acid in mice was inhibited by 50 and 69 % at 50 and 100 mg carrot

seed volatile oil/kg, respectively, indicating analgesic activity (Porchezhian et al. 2000).

Larvicidal Activity

Amyris balsamifera, *Daucus carota* and *Pogostemon cablin* essential oils showed 100 % larvicidal activity against *Culex pipiens pallens* (Park and Park 2012). Among the tested oils, the larvicidal activity of *D. carota* oil was the strongest followed by *P. cablin* and *A. balsamifera*. Carotol from carrot, showed >90 % mortality against *C. pipiens pallens* at 0.1 mg/mL. In acute toxicity testing of the water flea, *Daphnia magna*, *P. cablin* oil was the most toxic followed by *A. balsamifera* and *D. carota*. Among the isolated compounds, carotol was the most toxic to water fleas.

Abortifacient/Antifertility Activity

Alcoholic carrot seed extracts were found to possess extremely weak oestrogenic activity (Sharma et al. 1976). The extract significantly inhibited the uterotropic effect of 17β-oestradiol in the 3-day antioestrogenic assay. Oral administration of the extract from days 4 to 6 post-coitum in doses of 80 and 120 mg/mouse effectively inhibited implantation. However, oral administration on days 8–10 post-coitum did not affect pregnancy. The administration of carrot seed alcoholic extract at a lower dose showed anti-implantational activity, whereas higher doses caused foetus resorption (Bhatnagar 1995). The main effect of the extract appeared to be an abortifacient activity. At higher dose levels the extract demonstrated an oestrogenic nature with a prolonged estrous phase, whereas lower doses showed an antioestrogenic nature and an increase in the percentage duration of the dioestrous phase of the oestrous cycle. The petroleum ether extract and fraction 5 (fatty acids) of carrot seeds arrested the normal oestrous cycle of adult mouse and reduced the weight of ovaries significantly (Majumder et al. 1997). The cholesterol and ascorbic acid content in ovaries were significantly elevated by both treatment with extract and fraction 5 (fatty acids) of carrot seeds. The significant inhibition of Δ5,3-β-hydroxy steroid dehydrogenase and glucose 6-phosphate dehydrogenase, the two key enzymes involved in ovarian steroidogenesis, was also observed in mouse ovaries after 15 days of treatment. Results suggested that the fraction 5 (fatty acids) present in carrot seeds acted as an antisteroidogenic agent.

Adverse Intake Effect

A case of carotinaemia in a patient with excessive β-carotene food intake (approximately 1 kg per day carrots), diabetes mellitus and physiological amenorrhea was reported (Mikkelsen et al. 2009). The patient developed yellow discolouration in the palms and the soles of her feet. Blood samples showed a significantly increased level of serum β-carotene, but normal vitamin A value and liver enzymes. The status of physiological amenorrhoea and dysregulated diabetes mellitus may have deteriorated the yellow discolouration of the skin. A case of excessive carrot ingestion (6–7 lb of carrots per week to facilitate dieting) by a 48-year-old male was reported by Sansone and Sansone (2012). He suffered abdominal discomfort and had yellow/orange skin discolouration and was diagnosed with constipation, hypercarotinaemia and possible vitamin A toxicity. Following the cessation of excessive carrot ingestion, his liver enzymes normalised within 1 month.

Allergy Issues

Carrot allergen, a 16-kDa protein, was identified as a major IgE-binding component and designated Dau c 1 (Hoffmann-Sommergruber et al. 1999). Cross-inhibition assays verified the existence of common B-cell epitopes present on Dau c 1, Api g 1 as well as on Bet v 1. Dau c 1 was reported as a major allergen of carrot displaying IgE cross-reactivity with the homologous major birch pollen allergen Bet v 1 (Marković-Housley

et al. 2009). The structure of Dau c 1 was similar to those of the major allergens from celery, Api g 1, and birch pollen, Bet v 1. It was found that the majority of carrot-allergic patients had Bet v 1 cross-reactive IgE antibodies, whereas others had Dau c 1-specific IgE antibodies which did not recognise Bet v 1. Up to 25 % of food allergic subjects in central Europe suffer from carrot allergy and two isoforms of the major carrot allergen Dau c 1 had been described: Dau c 1.01, comprising five variants (Dau c 1.0101–Dau c 1.0105) and Dau c 1.02 (Wangorsch et al. 2012). Dau c PRP-like protein was identified as a new allergenic isoform, Dau c 1.03, in carrot roots. 68 % of carrot-allergic patients were sensitised to rDau c 1.03. The IgE reactivity of rDau c 1.03 is strongly correlated with reactivity to rDau c 1.0104, but not to rDau c 1.0201. The IgE reactivity of rDau c 1.03 is strongly correlated with reactivity to rDau c 1.0104, but not to rDau c 1.0201. They asserted that the epitope diversity of different Dau c 1 isoforms should be considered for component-resolved diagnosis and gene silencing of carrot allergens.

Traditional Medicinal Uses

The carrot plant is reported to be anthelmintic, carminative, deobstruent, diuretic, galactogogue, ophthalmic and stimulant (Grieve 1971; Lust 1974; Launert 1981; Chiej 1984; Duke and Ayensu 1985). Carrot is used in the traditional medicine for the treatment of gastric disorders, viz., acidity and gastric ulcer (Nayeem et al. 2010), and carrot acts as a diuretic, soothes the digestive tract and stimulates the uterus (Bown 1995). Plant infusion is used in the treatment of various complaints including digestive disorders and kidney and bladder diseases and in the treatment of dropsy (Grieve 1971; Bown 1995). Grated carrot has been used to treat threadworm infection (Chevallier 1996). Carrot leaf infusion has been used to counter cystitis and kidney stone formation (Chevallier 1996). Carrot seeds are diuretic (Duke and Ayensu 1985), carminative, emmenagogue and anthelmintic (Grieve 1971; Duke and Ayensu 1985). Carrot seed infusion is used in the treatment of oedema, flatulent indigestion and menstrual problems (Bown 1995).

Other Uses

Certain varieties of carrots have been used as feed for horses and dairy cattle. Studies by Aimaretti et al. (2012) demonstrated that bioethanol can be obtained from carrot discards by enzymatic hydrolysis prior to compressing and filtering to obtain carrot must. In this way, fermentable sugars extracted increased 3.5 times, and the production of 77.5 L of ethanol for each ton of discarded carrots was achieved. This process yielded bagasse as by-product, which could be used for animal feed.

An essential oil obtained from the seed is used in perfumery and as a food flavouring (Uphof 1968; Bown 1995). The oil has also been used cosmetically in antiwrinkle creams (Bown 1995). Water extracts from the carrot seed exhibit plant growth inhibitory properties against cress, cucumber, onion and carrot in a dose-dependent manner (Jasicka-Misiak et al. 2005). The low molecular active component was identified as crotonic acid 9(*E*)-2-butenoic acid. The determined strong herbicidal properties of crotonic acid and its availability after release to soil combined with its high level in seeds suggested that it might be considered as an allelopathic and autotoxic factor in the seeds. In Ethiopia fruits are used against tapeworm.

Studies showed that carrot waste materials, namely, carrot stem powder and carrot leaves powder, could be used as a potential adsorbent for the removal of methylene blue and malachite green dyes from aqueous solution (Kushwaha et al. 2011). Yadav et al. (2007) reported the use of carrot and baker's yeast for the bio-reduction of prochiral ketones by carrot dehydrogenase enzymes to synthesise a wide range of chiral secondary alcohols of biological importance. Carrots were used to reduce cyclic amino ketones in high yields and enantiomeric excesses (Lacheretz et al. 2009). This cheap, eco-compatible and efficient reducing reagent allows the easy access to precursors of biologically active products.

Falcarindiol isolated from carrot root showed antifungal activity towards plant pathogens, *Mycocentrospora acerina* and *Cladosporium cladosporioides* (Garrod et al. 1978). The ED_{50} for inhibition of germination of chlamydospores of *M. acerina* was 31.8 µg/ml.

Comments

Daucus carota is a complex and variable species. On the basis of morphological (leaf and root) traits, two main categories of domesticated carrots were reported (Small 1978):

Var. *sativus* refers to carrots originating from the West and exhibiting orange, yellow or sometimes white roots and highly indented, nonpubescent, yellow-green foliage.

Var. *atrorubens* refers to carrots originating from the East, exhibiting yellow, reddish-purple to purple-black, rarely yellowish-orange storage roots and poorly indented, grey-green, pubescent foliage.

Many intermediate variants exist between these two types. Wild carrots proved to be separable into two overlapping comprehensive groups, which were informally labelled subspecies aggregate *gingidium* and subspecies aggregate *carota* (the latter assemblage also encompassing the cultigens).

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Pastinaca sativa

Scientific Name

***Pastinaca sativa* L.**

Synonyms

Anethum pastinaca Wibel (illeg.), *Elaphoboscum sativum* (L.) Rupr., *Peucedanum pastinaca* (L.) Benth. Hook. f., *Peucedanum sativum* (L.) Benth. Hook. f., *Selinum pastinaca* (L.) Crantz.

Family

Apiaceae

Common/English Name

Parsnip

Vernacular Names

Afrikaans: Witwortel
Albanian: Pastinakë
Arabic: Gazar Abiad
Armenian: Varot
Austrian: Pastinake
Belarusian: Pasternak Pasjany
Belgium: Pastenaak
Brazil: Chirivia
Bulgarian: Paštărnak, Pshturnak
Catalan: Pastenage, Xirivia
Chinese: Bai Sun, Mei Guo Fang Feng, Ou Fang Feng
Croatian: Pastrnjak
Czech: Pastinák, Pastinák Lucni Setý, Pastinák Setý
Danish: Almindelig Pastinak**,** Pastinak
Dutch: Gewone Pastinaak, Pastinaak
Eastonian: Aed-Moorputk, Moorputk, Pastinaak
Esperanto: Pastinako
Finnish: Palsternakka, Ruokapasternakka
French: Pastenaque, Panais, Patennais
Gaelic: Cuirdín Bán, Meacan Bán
Galician: Cherouvea
Georgian: Dzirtetre, Pasternaki
German: Echte Pastinake, Gemeiner Pastinak, Gemüse-Pastinak, Hammelmöhre, Moorwurzel, Pastinake, Pastinak
Greek: Elaphovoskon
Hungarian: Kerti Pasztinák, Paszternák, Pasztinák
Icelandic: Nípa
India: Gujur (Hindu)
Italian: Carota Rossa, Pastinacá
Japanese: Paasunitpu
Kazakh: Pasternak Posevnoj
Kirghiz: Pasternak
Korea: Bangphung
Latvian: Pastinaki, Pastinaks
Lithuanian: Paprastasis, Pastarnokas, Pastarnokai
Macedonian: Običen Paškanat
Malaysia: Parsnip
Maltese: Pastinakka

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Nepali: Gujar
Niuean: Pāsinipi
Norwegian: Pastinakk
Polish: Pasternak Zwyczajny
Portuguese: Chirivia, Pastinaca, Pastinaga
Romanian: Păstârnac, Păstirnac, Păstirnac Commun
Russia: Pasternak Posevnoj
Serbian: Pastrnjak, Paškanat, Obični
Slovaščina: Fleischmannov Rebrinec, Navadni Rebrinec, Rebrinec Navadni
Slovencina: Paštrnák Siaty
Spanish: Pastinaca, Chirivía
Swedish: Palsternacka
Swiss: Pastenaque
Turkish: Akhavuç, Akkök, İğkök, Koyun Havucu, Yabani Havoc
Welsh: Llysiau Gwyddelig, Llysiau Gwynion Y Gerddi, Moron Gwynion, Moronen Y Moch, Panasen, Panasen Wyllt
Yiddish: Pasternak
Yugoslavia: Pastinak, Navadni Rebrinek
Zulu: Ipasinipu

Origin/Distribution

Wild distribution of parsnip occurs in Europe to Caucasus, Anatolia, Lebanon and Western Siberia. Parsnip has naturalised in many temperate areas and can be found in disturbed open areas, such as along railway embankments, roadsides, trails, riverbanks, ditches, beaches, sloughs, forest clearings, abandoned mine sites, quarries and other waste areas, gardens, meadows, swampy lowlands and grassy area. Parsnip is cultivated in the temperate region worldwide and in the cooler highlands above 900 m in the tropics and subtropics. It is mainly grown in home gardens and for specialty markets.

Agroecology

A cool temperate climate is required by parsnip. It prefers full or partial sun, moist to mesic conditions and fertile loamy soil. The plant also tolerates other types of soil.

Edible Plant Parts and Uses

Parsnip can be eaten raw, cooked, boiled, fried or roasted (Grieve 1971; Launert 1981; Facciola 1990). The roots are sweeter than carrots. The root is delicious baked; it can also be used in soups, stews, salads, casseroles, pies and puddings and dried for seasoning soups and processed for canning. Parsnip is also used for making jam, marmalade preserve and sweet flour for cakes. Parsnip is eaten with salt fish and boiled eggs during Lent. Roasted parsnip is considered an important ingredient in Christmas dinner and is featured in the traditional Sunday roast.

Parsnip is also used for making beer and wine in Britain and Ireland. In Ireland, cottagers make a beer by boiling the roots with water and hops and afterwards fermenting the liquor. In the north of Ireland, they have been often brewed with malt instead of hops and fermented with yeast, the result being a pleasant drink. Parsnip wine, when properly made, is esteemed by many people; the quality has been said to approach the famed Malmsey of Madeira.

Leaves and young shoots are cooked with other greens as a vegetable or added to soups. The seed is used as a condiment and has similar taste as dill.

Botany

A robust, biennial or short-lived monocarpic herb 1–1.6 m high. Root yellowish white, up to 30 × 10 cm, stout fleshy, broad proximally and tapering distally (Plate 1) becoming fibrous and tough with age. The stems are erect, glabrous to sparsely hairy, angular and furrowed. The basal and lower cauline leaves are oddly pinnate, oblong ovate in outline 20–30 × 10–16 cm with nine sessile leaflets, ovate–oblong, lobed, 5–8 long by 2.4–4 cm wide, obtuse, base obliquely subcordate, the terminal segment cuneate. Petioles subterete, basal sheathes 3–4 cm long. Upper cauline leaves gradually reduced in size and sessile. Flowers greenish yellow, pedicellate, in compound umbels 4–9 cm across, umbellets 15–30, consisting of 12–40 flowers. Terminal

Plate 1 Parsnip roots

(primary) umbels with fertile bisexual flowers with oblong hypanthia towards the outside and staminate flowers towards the centre. Lateral umbers (secondary and tertiary) with more staminate flowers and less bisexual flowers. Flower, 4–5 mm, with five yellowish-green petals, a greenish-yellow nectar pad and insignificant, reduced sepals. Stamens 5, carpel 1 with bilocular ovary. Fruit a glabrous schizocarp, 5–6 × 4–6 mm, dorsally flattened and ribbed, splitting into two mericarp, each with one, pale brown, oval or globose, narrowly winged seed.

Nutritive/Medicinal Properties

Root Nutrient/Phytochemicals

The nutrient composition of parsnip was reported as water79.53 g, energy75 kcal (314 kJ), protein 1.20 g, total lipid (fat) 0.30 g, ash 0.98 g, carbohydrate17.99 g, total dietary fibre 4.9 g, total sugars 4.80 g, calcium 36 mg, iron 0.59 mg, magnesium 29 mg, phosphorus 71 mg, potassium 375 mg, sodium 10 mg, zinc 0.59 mg, copper 0.120 mg, manganese 0.560 mg, selenium 1.8 µg, vitamin C, 17.0 mg, thiamine 0.090 mg, riboflavin 0.050 mg, niacin 0.700 mg, pantothenic acid 0.600 mg, vitamin B6 0.090 mg, total folate 67 µg, vitamin E (α-tocopherol) 1.49 mg, vitamin K (phylloquinone) 22.5 µg, total saturated fatty acids 0.050 g, 14:0 (myristic) 0.003 g, 16:0 (palmitic) 0.030 g, 18:0 (stearic) 0.014 g, total monounsaturated fatty acids 0.112 g, 16:1 undifferentiated (palmitoleic) 0.003 g, 18:1 undifferentiated (oleic) 0.102 g, total polyunsaturated fatty acids 0.047 g, 18:2 undifferentiated (linoleic) 0.041 g and 18:3 undifferentiated (linolenic) 0.003 g (USDA-ARS 2014). Vacuolar membranes of parsnip, parsley and carrot roots contained a high level of unsaturated fatty acids (up to 78 % of total fatty acids) (Makarenko et al. 2007). In parsnip linoleic acid (53.5 %) predominated, followed by high level of hexadienoic acid (C16:2 ω6) (8 %), followed by α-linolenic acid (4.4–7.3 %) in parsley and parsnip. Palmitic acid predominated among the saturate fatty acids. Parsnip also contained the flavonol quercetin 1 mg (Lugasi and Hovari 2000).

Five furanocoumarins, imperatorin, bergapten, isopimpinellin, xanthotoxin and sphondin, were identified and quantified in the intact seeds of wild and cultivated parsnip (Berenbaum et al. 1984). Fruits were found to contain the following furanocoumarin: psoralen, xanthotoxin, bergapten, angelicin, imperatorin, isobergapten and isopimpinellin (Berenbaum et al. 1991). Five biologically active furanocoumarins (psoralen, bergapten, xanthotoxin, trioxsalen and angelicin) were found in celery and parsnips (Lombaert et al. 2001). Of 110 parsnips samples, 109 (99 %) contained quantifiable levels of furanocoumarins. The mean level of total furanocoumarins in the positive parsnip samples was 15.1 µg/g; the maximum level detected was 145 µg/g. Xanthotoxin and bergapten were the most commonly detected furanocoumarins in both celery (68 % and 63 %) and parsnips (97 % and 96 %).

Four linear furanocoumarins (psoralen, xanthotoxin, isopimpinellin and bergapten) were identified on the surfaces of callus cells of *Pastinaca sativa* in the concentration range of 0.055–1.1 µg total/g fresh weight (Zobel and Brown 1993). Shake cultures produced up to two orders of magnitude more furanocoumarins than callus cells, and extrusion was accelerated, but the concentrations of particular exported furanocoumarins varied, again pointing to selective extrusion. Parsnip tissues cultured in-vitro were found to produce furanocoumarins psoralen, bergapten, xanthotoxin, isopimpinellin and umbelliferone

(Ekiert and Gomolka 2000a), bergapten, xanthotoxin, isopimpinellin and sphondin (Ekiert and Gomolka 2000b). Total content of coumarins ranged from 115.7 to 408.5 mg/100 g of the dry weight; isopimpinellin predominated quantitatively (maximum content of 238.9 mg/100 g) followed by psoralen (maximum content of 108.8 mg/100 g). Imperatorin was not detected in callus tissues although it dominated in the analysed fruits of the studied plant (200.0 mg/100 g). Ostertag et al. (2002) found that furocoumarin concentrations (sum of five furocoumarins: angelicin, isopimpinellin, 5-methoxypsoralen, 8-methoxypsoralen and psoralen) in freshly harvested parsnips was generally lower than 2.5 mg/kg, and storage of parsnips in any form investigated at −18 °C over up to 50 days did not lead to a marked increase in furocoumarin levels. In contrast, storage of whole parsnips, but not of cubes or homogenate, at +4 °C resulted in a marked biphasic increase of furocoumarin concentrations after 7 and 38 days of storage up to levels of about 40 mg/kg. A dramatic increase in furocoumarin concentrations up to 566 mg/kg was observed when whole parsnips obtained from the market were kept at room temperature over 53 days, resulting in a visible microbial (mould) infection.

Parsnip roots inoculated with several nonpathogenic fungi afforded a 20-fold increase in the phytoalexin, xanthotoxin; other furanocoumarins detected included bergapten, isopimpinellin, angelicin, psoralen and imperatorin (Johnson et al. 1973). Ceska et al. (1986) found that furocoumarin contents in spoiled and diseased parsnip roots were increased 25-fold over normal levels. Mixed crystals of furocoumarins such as angelicin, psoralen, 5-methoxypsoralen and 8-methoxypsoralen could be detected on the surfaces of the parsnip roots. Parsnip roots infected with *Fusarium sporotrichioides* accumulated high levels of fungitoxic furanocoumarins mainly xanthotoxin and angelicin (Desjardins et al. 1989). Copper chloride and fungal (*Bipolaris sorokiniana* and *Alternaria* spp.)-treated root slices of parsnip were found to produce the following furanocoumarins xanthotoxin, isompinellin, angelicin, bergapten, sphondin, pimpinellin and isobergapten (Al-Barwani and Eltayeb 2004). However, isoimperatorin earlier reported to be a constituent of parsnip root was not detected. Xanthotoxin angelicin and psoralen were the major phytoalexins induced in parsnip roots by the fungus *Bipolaris sorokiniana.* Treatment with however copper chloride resulted in the accumulation of xanthotoxin and isopimpinellin as the major induced compounds, while psoralen was not detected. Induction of parsnip roots with copper chloride resulted in a 20 to 29-fold increase in the amounts of xanthotoxin.

Polyacetylenes, falcarinol and falcarindiol were isolated from parsnip root nonpolar extract (Zidorn et al. 2005). Parsnip contained the highest amount of falcarinol and falcarindiol, followed by carrot and fennel. Polyacetylenes, i.e. falcarinol, falcarindiol and falcarindiol-3-acetate, were found in parsnip (Kramer et al. 2011). Distribution of total polyacetylenes as well as individual compounds was confirmed in parsnip roots using nondestructive Raman analysis (Roam et al. 2011). Blanching (95 °C) had the greatest influence on the retention of polyacetylenes in sous vide (90 °C 10 minutes) processed parsnip discs resulting in significant decreases of 24.5 and 24 % of falcarinol and falcarindiol, respectively (Rawson et al. 2010). Subsequent anaerobic storage of sous vide processed samples resulted in a significant decrease in falcarinol contents but elicited no change in falcarindiol content. Falcarinol contents in water immersion (WI, 70 °C for 2 minutes) processed samples were significantly higher than in sous vide samples. Falcarindiol was particularly susceptible to aerobic storage following WI processing with losses of up to 70 % occurring after 5 days storage. When thermally treated, falcarinol-type polyacetylene underwent degradation such as oxidation and dehydrogenation forming oxidised form of falcarinol-type molecules, in this case falcarindione, dehydrofalcarinol and dehydrofalcarinone. Thermal processing impacted significantly on colour of parsnip samples compared to minimally processed in both sous vide and WI processed samples resulting in parsnip discs becoming darker, yellower and browner following processing and storage. Absolute configuration of falcarinol

(9Z-heptadeca-1,9-diene-4,6-diyn-3-ol) from *Pastinaca sativa* was found to have a 3R absolute configuration (i.e. (3R, 9Z)-heptadeca-1,9-diene-4,6-diyn-3-ol) (Corell et al. 2013). Aliphatic C (17)-polyacetylenes of the falcarinol type, found in common food plants of the Apiaceae family such as carrot, celeriac, parsnip and parsley, had demonstrated interesting bioactivities including antibacterial, antimycobacterial and antifungal activity as well as anti-inflammatory, antiplatelet, antiaggregatory, neuritogenic and serotonergic effects (Christensen 2011).

The essential oil from the fully grown root was found to be rich in myristicin and terpinolene (together 80–88 %), forming the major components in the essential oil from fresh parsnip roots (Kubeczka and Stahl 1975). Minor components included mono- and sesquiterpene hydrocarbons such as (*E*)-β-farnesene, β-bisabolene, β-sesquiphellandrene and γ-palmitolactone. The composition of essential oils in parsnip roots changed with plant developmental stages; at the seedling stage (0–18 days), the primary oil ducts between the pericycle cells contained mainly sesquiterpene hydrocarbon *trans*-β-farnesene (34.9 %), with smaller amounts of myristicin (14.4 %) and terpinolene (3.1 %); as the roots thicken during the secondary stage (23–30 days), the sesquiterpene content decreases, whereas the myristicin and terpinolene contents increased; and at the adult stage (38–160 days) with the development of secondary oil ducts, the level of sesquiterpene declined to 1.5 %, while that of myristicin and terpinolene increased to 62.6 and 25.5 %, respectively (Stahl-Biskup and Wichtmann 1991). The essential oil from the fully grown parsnip root was found to be rich in myristicin and terpinolene and contained minor amounts of (*E*)-β-farnesene, β-bisabolene, β-sesquiphellandrene and γ-palmitolactone (Lawrence 2002).

The coumarins *p*-coumaric acid and umbelliferone were found to be the precursors of furanocoumarins bergapten, imperatorin, isopimpinellin and xanthotoxin in parsnip (Brown 1970). Two α- hydroxyisopropyldihydrofuranocoumarin appeared to be natural intermediates in the biosynthesis of linear and angular furanocoumarins (Steck 1969). Angelicin synthase, alternative name Cytochrome P450 CYP71AJ4, was isolated from *P. sativa* and found to be involved in angular furanocoumarin biosynthesis (Larbat et al. 2009). It converted (+)-columbianetin to angelicin and produced hydroxycolumbianetin as a by-product. The reaction mechanism was initiated by the elimination of syn-C-3′-hydrogen from C-3′. It exhibited no activity with demethylsuberosin, (+)-marmesin, 5-hydroxymarmesin, psoralen, bergaptol, xanthotoxol, bergapten, xanthotoxin, isopimpinellin, cinnamic acid, 4-coumaric acid, 2-coumaric acid, ferulic acid, coumarin, herniarin, scopoletin or umbelliferone.

Parsnip was found to contain minute amounts (8 ng/g) of the steroid 5a-androst-16-en-3-one, known as a boar pheromone which contributed to its characteristic fragrance (Claus and Hoppen (1979).

Finely powdered suberin from six root crops including *Pastinaca sativa* was fractionated into phenolic (<10 %) and aliphatic (13–35 %) fractions (Kolattukudy et al. 1975). The aliphatic fractions consisted mainly of ω-hydroxy acids (29–43 %), dicarboxylic acids (16–27 %), fatty acids (4–18 %) and fatty alcohols (3–6 %). Among the fatty acids, very long chain acids (>C_{20}) were the dominant components in all six plants. Among the alcohol fraction, C_{18}, C_{20}, C_{22} and C_{24} saturated primary alcohols were the major components. C_{16} and C_{18} dicarboxylic acids were the major dicarboxylic acids of the suberin of all six plants, and in all cases octadec-9-ene-1, 18-dioic acid was the major component except in rutabaga. The composition of the ω-hydroxy acid fraction was quite similar to that of the dicarboxylic acids; 18-hydroxy-octadec-9-enoic acid was the major component in all plants except rutabaga.

The amount of wax extracted from the periderm of parsnip storage organ was very small 49 mg/kg of chloroform-extractable material, equivalent to 49% weight of chloroform extract or 17 μg/cm^2 was/ surface area (Espelie et al. 1980). The composition of parsnip wax comprised 50 % hydrocarbon, 1.1 % wax ester, 9 % fatty alcohol, 25 % fatty acids and 15 % unknown component. The hydrocarbons from the suberin

layer had a broader chain-length distribution, a predominance of shorter carbon chains and a higher proportion of even-numbered carbon chains than the leaf alkanes from the same plant. Parsnip suberin alkanes had 33 % even-chain homologs. The proportion of alkanes shorter in chain length than C_{29} was 34 % for the suberin wax of parsnip. Chain-length distributions of the fatty alcohols, fatty acids, ω-hydroxy acids and dicarboxylic acids in the polar fraction of the $CHCl_3$ extract of parsnip storage organ were 0.07 %, 1.11 %, 0 % and 0 % respectively. In parsnip, the major free and esterified fatty acids comprised a higher proportion of longer-chain components, where C22 and C24 comprised slightly more than 15 % each of the free fatty acid fraction but 2 % or less of the esterified acids.

Fruit/Bud/Aerial Parts Phytochemicals

Furanocoumarin compounds reported from the roots, stems, leaves, buds, flowers, fruits or seeds of wild parsnip included: angelicin (angular), apterin (angular), bergapten (linear), imperatorin (linear), isobergapten (angular), isoimperatorin (linear), isopimpinellin (linear), pimpinellin (angular), psoralen (linear), sphondin (angular), xanthotoxin (linear) and xanthotoxol (linear) (Pathak et al. 1962; Berenbaum 1985; Berenbaum and Zangerl 1986). There is considerable variation in the toxicity and photoactivity of these different furanocoumarin compounds (Berenbaum et al. 1991). The linear furanocoumarins were reported to be highly toxic to diverse herbivores and pathogens, but the angular types were generally less reactive (Scott et al. 1976) and may possess additional (deterrent), complementary or synergistic effects (Berenbaum and Feeny 1981; Berenbaum 1985).

The composition of essential oils from different parts of fresh plants of *Pastinaca sativa* revealed the existence of four chemotypes: plants with high and low amount of myristicin and plants with and without acetic acid esters of aliphatic C8 and C10 alcohols in the fruit oil (Stahl and Kubeczka 1978, 1979). Terpene hydrocarbons *cis*-β-ocimene, *trans*-β-ocimene, terpinolene and *trans*-β-farnesene were identified besides γ-palmitolactone, in the essential oil of the aerial parts (Kubeczka and Stahl 1977). Additional minor amounts of several mono- and sesquiterpene hydrocarbons, myristicin and an unknown diterpene alcohol were also detected.

Light and nutrient availability jointly affected the concentration of four of the six furanocoumarins in parsnip aerial parts (with exception of sphondin and angelicin) (Zangerl and Berenbaum 1987). UV radiation increased the level of all six except imperatorin and sphondin and also influenced the relative amounts of furanocoumarins. Furanocoumarins being UV phototoxic to many organisms, including insects, the response of parsnip plants to UV radiation may affect their resistance to herbivores.

Metabolites (mean values in μg/mg dry weight) detected in intact wild parsnip foliage and damaged (24 hours previously) foliage were determined, respectively, as follows: fatty acids, C16:0 (palmitic acid) (1.03, 1.19), C16:3 (hexadecatrienoic *acid*) (1.54,1.24), C18:0 (stearic acid) (0.85,0.62) and C18:1 (oleic acid) (4.50,3.97); sugars, glucose (6.19, 3.04), fructose (5.59,3.00), myoinositol (3.75, 3.49), sorbitol (0.52,0.38) and sucrose (1.34, 1.47); soluble protein (244,307); ascorbic acid (5.12,5.10); terpenes, *cis*-ocimene (1.68, 1.69), *trans*-ocimene (2.43,2.42) and farnesene (4.32,2.88); furanocoumarins, imperatorin (0.07,0.10), bergapten (0.32, 0.41), psoralen (0.15, 0.15), isopimpinellin (0.15, 0.16), xanthotoxin (1.01, 1.44) and sphondin (0.06, 0.10); palmitolactone (1.26,1.01); and myristicin (1.60, 1.31) (Zangerl and Berenbaum 1998). Significant damage-induced changes in foliage chemistry were observed for 7 of the 22 compounds quantified.

Highest relative furanocoumarin content (per cent dry weight) was found in parsnip buds, ripe seeds and flowers; in contrast furanocoumarin content was lowest in roots and stems (Berenbaum 1981). Leaves of rosette plants generally contained more furanocoumarins than did leaves of flowering plants; as leaves senesced, furanocoumarin concentrations declined, concomitant with increases in the stem and ripe seeds. Seeds at all

stages of maturity were remarkably uniform in furanocoumarin content. Xanthotoxin was the principal furanocoumarin in parsnip at all times during the season except during late May and early June when bergapten predominated. Xanthotoxin, bergapten and imperatorin were present at all stages of growth; two minor components, sphondin and angelicin, were present in the reproductive parts of some flowering plants. Allocation of nitrogen within the plant was significantly correlated with allocation of furanocoumarins. This relationship was especially prominent in late stages of development in flowering plants, when nitrogen, along with furanocoumarins, was transferred from senescent leaves to seeds.

Across all umbel orders (primary, secondary and tertiary) and male and female floral stages, the range of mean relative furanocoumarin proportions in the flowers for angelicin was <0.01–0.1 %, imperatorin 20.9–53.3 %, bergapten 9.8–15.4 %, isopimpinellin 8.1–21.2 %, xanthotoxin 23.4–51.9 %, sphondin 1.1–2.4 % and psoralen <0.1–5.3 % (Nitao 1988). Defloration of the primary umbel at either the bud or female flower stage failed to alter total furanocoumarin concentration in the seeds; the range of mean relative proportions in the seeds were for angelicin 1.0–1.7 %, imperatorin 27.2–33.0 %, bergapten 18.7–22.3 %, isopimpinellin 10.7–19.8 %, xanthotoxin 29.8–38.0 % and sphondin 1.0–1.8 %. No psoralen was detected in the seeds.

The characteristics of the floral fragrances of flowers, buds and leaves of Apiaceous plants including *Pastinaca sativa* were found to originate in differences in the proportions of the monoterpene hydrocarbons, among which α-pinene, β-pinene, *cis*-β-ocimene, *trans-β-ocimene*, limonene, sabinene and myrcene dominated (Borg-Karlson et al. 1993). Volatile compounds including aliphatic hydrocarbons, terpenoids, aromatic compounds and nitrogenous compounds were found. The terpenoid, linalool, a known marker pheromone in solitary bees was also detected. *Heracleum sibiricum* and *P. sativa* had very similar fragrances.

The concentration of the furanocoumarins psoralen, xanthotoxin and bergapten on the leaf surfaces of *Pastinaca sativa was* 0.12 μg/g (25 % of total) (Zobel et al. 1990). Eight coumarins found occurring with psoralen, xanthotoxin and bergapten on leaf surfaces were identified as the simple coumarins scopoletin, scoparone and osthol; the linear furanocoumarins imperatorin and phellopterin; the angular furanocoumarins angelicin and pimpinellin; and the pyranocoumarin seselin (Zobel et al. 1990).

Mono- and sesquiterpenes were abundant in buds but absent from female flowers and green fruits (Zangerl et al. 1997). The aliphatic esters octyl acetate and octyl butyrate were found as the only essential oil components found exclusively within tissues consumed by the webworm, *Depressaria pastinacella*; both esters were found to be produced only in reproductive tissues. Furanocoumarins, which were found in all organs, were present at low concentration in buds, at intermediate concentrations in female flowers and at highest concentrations in fruits. Among the primary metabolites, developmental shifts were, for the most part, quantitative. Soluble protein and fatty acid content declined with development. A qualitative change in fatty acid composition was observed in that linolenic acid in buds was replaced by petroselinic acid in fruits.

In a study of resistance of parsnip chemotypes to parsnip webworm, *Depressaria pastinacella*, 22 metabolites were detected in the buds, flower and young fruits (Zangerl and Berenbaum 2004). Parsnip webworm had been found to feed exclusively on the buds, flowers and green fruits. The chemotypes differed significantly for 14 of the 22 constituents, including 4 nutrients. The secondary metabolites found included furanocoumarins (imperatorin, bergapten, xanthotoxin, sphondin, psoralen and isopimpinellin), the coumarin osthol (not present in bud), terpenes (*cis*- and *trans-ocimene*, caryophyllene, bergamotene, cubebene and farnesene), the phenylpropanoid myristicin (not present in fruit) and three fatty acid derivatives (palmitolactone, octyl acetate and octyl butyrate). The primary metabolites found included: soluble protein, sugars (fructose, glucose, sorbitol, myoinositol), phytic acid and saturated and unsaturated C18 fatty acids.

Constituents that distinguished resistant individuals from susceptible ones were high levels of osthol, octyl butyrate and fatty acids in developing fruit, as well as high levels of linear furanocoumarins in buds and high bud caryophyllene combined with low bud protein. Conversely, susceptibility was associated with overall average chemical composition and with high levels of bergamotene, cubebene, myristicin and palmitolactone in buds and high protein in both buds and fruit. Significant heritabilities were found for unsaturated C18 fatty acids in both buds and developing fruits; stearic acid in developing fruits, fructose and sorbitol in buds; fructose in fruits, myoinositol in fruits; and bergapten and psoralen in fruits.

Furanocoumarins bergapten and imperatorin were isolated from the fruits (Soine et al. 1956). Flavonoids were detected in the fruit (Maksyutina and Kolesnikov 1962). From the fruits of *P. sativa*, subsp. *sylvestris*, the bergapten, imperatorin, isopimpinellin and xanthotoxin were isolated; their contents were found to be higher than in the fruits of other varieties of *Pastinaca* gathered in the same season. Sphondin was also identified (Stein and Posocco 1984). Surface concentrations of linear furanocoumarins (psoralens) varied between traces and 40 μg/g of the mature parsnip fruits or seeds, amounting to 0.38–43 % of the total. In the whole, fruits concentrations were very high in *Pastinaca sativa* reaching levels of milligrams per gram fresh weight of fruits (Zobel and Brown 1991). The chemical content (μg/mg dry fruit) of octyl esters and furanocoumarins in mature wild parsnip fruits were: octyl acetate 1.56 μg, octyl butyrate 4.28 μg, bergapten 1.85 μg, imperatorin 3.72 μg, sphondin 0.31 μg and xanthotoxin 4.02 μg (Carroll et al. 2000). From the essential oil of fruits, the aliphatic esters butyl butyrate, hexyl butyrate and decyl butyrate and decyl acetate and the free alcohols hexanol-(1) and decanol-(1) were identified besides octenol-(1), the acetic, butyric and caproic acid esters, respectively, several terpene hydrocarbons and myristicin (Kubeczka and Stahl 1977).

The coumarin osthole was detected in the seed (Maksyutina 1967). Three flavonoid glycosides, hyperin, rutin and pasternoside, were isolated from the seeds (Maksyutina and Litvinenko 1966). Structure of pastenoside was elucidated as isorhamnetin 3-β-D-glucopyranoside 4′-α-l-rhamnopyranoside. Enzymatic hydrolysis of pasternoside yielded the monoglycoside deglucopasternoside, with the structure, isorhamnetin4′-α-L-rhamnopyranoside.Furanocoumarins imperatorin, bergapten, isopimpinellin, xanthotoxin and sphondin were found to be restricted to the vittae or oil tubes within the ripe seeds of wild parsnip; the furanocoumarin content and composition of these organs varied with their location (Berenbaum and Zangerl 1986). Eighteen components were characterised in parsnip seed essential oil representing 95 % of the oil with octyl butyrate (79.5 %) and octyl hexanoate (5.3 %), as the major constituents (Kurkcuoglu et al. 2006). Other components were: hexyl butyrate (3.3 %) phenylethyl butyrate (2.2 %), octanol (1.4 %), decyl butyrate (1.3 %), decanal (0.6 %), octanal (0.3 %), octyl acetate (0.3 %), (*Z*)-β-ocimene (0.2 %), butyl butyrate (0.1 %), α-zingiberene (0.1 %), β-sesquiphellandrene (0.1 %), *ar-curcumene* (0.1 %), benzyl butyrate (0.1 %), (*e*)-nerolidol (0.1 %), phenylethyl hexanoate (0.1 %) and decanol (<0.1 %).

Anticancer Activity

Studies demonstrated that isopimpinellin and imperatorin could effectively inhibit DMBA (7,12-dimethylbenz[a]anthracene) and benzo[a] pyrene (B[a]P) skin tumour initiation when given orally and have little or no systemic toxicity in mice at relatively high doses (Kleiner et al. 2002). Orally administered isopimpinellin and imperatorin significantly inhibited B [a] P-DNA adduct formation by 37 % and 26 %, respectively. Imperatorin also blocked DMBA-DNA adduct formation by 43 %. Isopimpinellin significantly reduced the mean number of papillomas per mouse by 49, 73 and 78 % compared to corn oil controls at 30, 70 and 150 mg/kg body wt, respectively. Orally administered isopimpinellin also significantly reduced the percentage of mice with papillomas at the highest dose tested (150 mg/kg). Of the polyacetylenes isolated, falcarinol proved to be the most active compound with a pronounced toxicity against acute lymphoblastic

leukaemia cell line CEM-C7H2, with an IC_{50} of 3.5 µmol/L (Zidorn et al. 2005). *P. sativa* ethanol extract exhibited varying degree of apoptotic activity in-vitro against ML-1 human acute myeloblastic leukaemia, J-45.01 human acute T cell leukaemia, EOL human eosinophilic leukaemia, HL-60 human Caucasian promyelocytic leukaemia, 1301 human T cell leukaemia lymphoblast, C-8166 human T cell leukaemia, U-266B1 human myeloma, WICL human Caucasian normal B cell and H-9 human T cell lines (Bogucka-Kocka et al. 2008).

Antimicrobial Activity

Angelicin and its derivatives showed antifungal activity against *Candida albicans*, *Cryptococcus neoformans*, *Saccharomyces cerevisiae* and *Aspergillus niger* in-vitro (Sardari et al. 1999). The furanocoumarins extracted from parsnip demonstrated antifungal activity against *Trichophyton mentagrophytes* var. *granulosum*, *T. tonsurans*, *T. mentagrophytes*, *T. mentagrophytes* var. *interdigitale*, *T. mentagrophytes* var. *asteroides* and *Microsporum gypseum* (Wolski et al. 2000).

Hyperpigmentation Activity

Pathak et al. (1962) reported the use of furocoumarin(psoralens),namely,psoralen,8-methoxypsoralen (xanthotoxin) and 5-methoxypsoralen (bergapten), in the treatment of vitiligo and as a means of increasing pigmentation after exposure to UV.

Allergy and Toxicity Issues

Parsnip root was found to contain three photoactive, mutagenic and photocarcinogenic psoralens, psoralen, xanthotoxin (8-methoxypsoralen) and bergapten (5-methoxypsoralen), in a total concentration of about 40 ppm, and these were reported not to be destroyed by normal cooking procedures (boiling or microwave) (Ivie et al. 1981). Studies showed that dried healthy parsnip root tissue fed to male Swiss Webster mice for 30 days caused no significant histopathological changes in the oesophagus and forestomach (Mongeau et al. 1994). In the liver, the highest level (but neither of the two lower levels) of dried diseased parsnip root tissue led to swelling of the cytoplasm in cells surrounding the central vein of hepatic lobules, with consequent compression of the peripheral cells. Using [3H]thymidine radioautography, a dose-related increase in cell labelling with the level of diseased parsnip root tissue was demonstrated in the liver. Beattie et al (2007) reported that threshold erythema during high-dose UVA1 therapy of volunteers with skin types I and II was unaffected by ingestion of a 200 g portion of parsnip containing psoralen.

Occupational dermatitis from organically grown parsnip was reported by Aberer (1992). Lutchman et al. (1999) reported 11 patients who had been involved in harvesting parsnips for week in a local farm presented themselves in Ipswich Hospital, Suffolk, with phytophotodermatitis characterised by painful erythematous rash on their forearms and hands. It was suggested to be related to photosensitising furocoumarins in parsnip. A new case of systemic contact dermatitis caused by celeriac, parsnip and carrot in a patient was reported by Paulsen et al. (2013).

Traditional Medicinal Uses

It has been used in folk medicine for kidney disorders, jaundice and other maladies (Grieve 1971; Foster and Duke 1998). The root and leaves are diuretic. A tea made from parsnip root has been employed in the treatment of women's complaints, and a strong decoction has been used for intermittent fever. A poultice of the roots has been applied externally to inflammations and sores and to treat psoriasis and vitiligo. Oils extracted from parsnip seeds have been used to treat intermittent fever.

Other Uses

Roots and shoots serve as good animal feed especially for pigs and dairy cattle. The leafy shoots and roots are used to a domestic insect spray to

control aphids and red spider mites. Parsnips are not only a valuable item of human food, but equal, if not superior to carrots for fattening pigs, making the flesh white and being preferred by pigs to carrots. Washed and sliced and given with bran, horses eat them readily and thrive on them. In Brittany and the Channel Islands, they are largely given to cattle and pigs, and milch cows fed on them in winter are said to give as much and as good milk and yield butter as well flavoured as when feeding on grass in May and June grieve.

Furanocoumarins found in parsnip had been shown to be toxic or repellent to insects (Berenbaum 1978, 1981; Berenbaum et al. 1991; Carroll and Berenbaum 2002; Cianfrogna et al. 2002) and associated with resistance to a specialist insect herbivore *Depressaria pastinacella* (Berenbaum et al. 1986). Berenbaum et al. (1991) found that individually, none of the other furanocoumarins (bergapten, angelicin, imperatorin, isobergapten, isopimpinellin, psoralen) present in parsnip seeds was as toxic as the photosensitiser xanthotoxin against *Heliothis zea*. Nevertheless, the natural mixture of compounds was toxicologically more effective both in the presence and absence of UV light than was an equimolar amount of xanthotoxin. The difference in toxicity diminished with increasing light levels. Octyl butyrate, a known deterrent to webworm, *Depressaria pastinacella*, was found to be highly correlated with furanocoumarin content in parsnip and differed significantly among normal and parthenocarpic fruit, suggesting that webworms may be able to avoid furanocoumarins by virtue of their behavioural response to octyl butyrate (Cianfrogna et al. 2002). The aliphatic esters octyl acetate and octyl butyrate, found only in parsnip reproductive tissues (Zangerl et al. 1997), were found to be feeding deterrents, while octyl acetate also served as an olfactory attractant and octyl butyrate an olfactory repellent of parsnip by the webworm, *Depressaria pastinacella* (Carroll and Berenbaum 2002).

Comments

Parsnip is cultivated as a root vegetable and forage plant mainly in temperate regions worldwide, sometimes in the tropics and subtropics. It was an important vegetable and fodder plant in Western and Central Europe from the Middle Ages to the eighteenth century but had been largely replaced by potato and carrot.

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Alocasia macrorrhizos

Scientific Name

Alocasia macrorrhizos (**L**.) **G. Don**

Synonyms

Alocasia cordifolia (Bory) Cordem., *Alocasia grandis* N.E.Br. (illeg.), *Alocasia indica* (Lour.) Spach, *Alocasia indica* (Lour.) Schott, *Alocasia indica* var. *diversifolia* Engl., *Alocasia indica* var. *heterophylla* Engl., *Alocasia indica* var. *metallica* (Schott) Schott, *Alocasia indica* var. *rubra* (Hassk.) Engl., *Alocasia indica* var. *typica* Engl., *Alocasia indica* var. *variegata* (K. Koch & C.D. Bouché) Engl., *Alocasia macrorrhiza* (L.) Schott, *Alocasia macrorrhizos* var. *rubra* (Hassk.) Furtado, *Alocasia macrorrhizos* var. *ariegata* (K. Koch & C.D. Bouché) Furtado, *Alocasia marginata* N.E.Br., *Alocasia metallica* Schott, *Alocasia montana* (Roxb.) Schott, *Alocasia pallida* K. Koch & C.D. Bouché, *Alocasia plumbea* Van Houtte, *Alocasia rapiformis* (Roxb.) Schott, *Alocasia uhinkii* Engl. & K. Krause, *Alocasia variegata* K. Koch & C.D. Bouché, *Arum cordifolium* Bory, *Arum indicum* Lour., *Arum macrorrhizon* L., *Arum macrorrhizum* L., *Arum montanum* Roxb., *Arum mucronatum* Lam., *Arum peregrinum* L., *Arum rapiforme* Roxb., *Caladium indicum* K. Koch (inval.), *Caladium macrorrhizon* (L.) R.Br., *Caladium metallicum* Engl., *Caladium odoratum* Lodd., *Caladium plumbeum* K. Koch (inval.), *Calla badian* Blanco, *Calla maxima* Blanco, *Colocasia boryi* Kunth, *Colocasia indica* (Lour.) Kunth, *Colocasia indica* (Lour.) Hassk., *Colocasia indica* var. *rubra* Hassk., *Colocasia macrorrhiza* (L.) Schott, *Colocasia montana* (Roxb.) Kunth, *Colocasia mucronata* (Lam.) Kunth, *Colocasia peregrina* (L.) Raf., *Colocasia rapiformis* (Roxb.) Kunth, *Philodendron peregrinum* (L.) Kunth, *Philodendron punctatum* Kunth

Family

Araceae

Common/English Names

Ape, Big Rooted Taro, Egyptian Lily, Elephant's Ear, Giant Alocasia, Giant Elephant Ear, Giant Taro, Roasting Coco, Upright Elephant Ear

Vernacular Names

Arabic: El-Qulqass, El-Emlak
Australia: Cunjevoi (Aboriginal, S. Queensland)
Bangladesh: Mankachu (Bengali)
Brazil: Inhame Gigante, Inhame-Açú, Orelha-De-Elefante-Gigante, Taiá-Rio-Branco, Taioba
Burmese: Pein-Mohawaya, Pein-U

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Chinese: Hai Yu, Jia Hai Yu, Jian Wei Yu, Kuan Yin Lien, Lang Du, Lao Hu Yu, Tien Ho, Tu Chiao Lien, Shanyu
Chuukese: Fine, Kä, Ka, Kachik, Kalap, Kka, Oht, Oot, Pween, Pwerik
Cook Islands: Kape
Czech: Alokázie, Árón Italský
Danish: Kæmpetaro, Vikingeskjold
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Fais: Fila
Fijian: Via, Via Dalo, Via Gaga, Via Nganga, Viamila, Viadindi, Viandini, Viandranu, Viasori
Finnish: Jättialokasia
French: Alocasie, Alocasie Ŕ Grandes Racines, Alocasie Ŕ Grosse Racine, Grande Tayove, Taro Géant
French Haiti: mazumbel, mazoumbèl (Creole)
German: Alokasie
Guyana: Hog Tannia
India: Boro-Mankachu, Man Kachu (Assamese), Mankachu (Bengali),Cureas (Goan), Alavu, Manjand (Gujarathi), Alu, Mankind, Mankanda, Mankachu (Hindi), Baalaraaksha, Kare Menasangi, Manaka, Marasa Kaage, Marasanige, Mundi Gedde, Mundigida, Neerugenasu (Kannada), Kasali (Konkani), Erichebu, Marambu, Seema Chembu, Venal Chembu (Malayalam), Hongngoo (Manipuri), Aalu, Kaamsaalu, Kaasaalu, Kasali, Mansacchu (Marathi), Hastikarnah (Sanskrit), Veruku, Attikanni, Attikkani, Attikkanni, Avantikkanni, Kacakanni, Kacakarani, Kacakarni, Karanaippala, Karanippala, Karikanni, Kecakkanni, Koli, Merukankilanku, Meruku, Piracai, Piri, Tantikarni, Mucalam, Mucali, Verukankilanku, Viruku, Ulakkai (Tamil), Charakanda, Sarachema, Verrichama (Telugu), Chevu, Sevu (Tuli)
Hawaiian: ‘Ape, Ape Keoke, Apii
Hebrew: Alocasia
Hungarian: Táró
Ifaluk: File
I-Kiribati: Te Kabe, Babai’
Indonesia: Bira, Sente (Javanese), Hila, Kei, Kiha, Mira, Tofeka, Wir, Wire (Maluku), Biah, Mae, Mael, Sente, Wia (Nusa Tenggara), Biha, Bira, Lawira, Makata, Sente (Sulawesi), Ababa, Bira, Birah (Sumatra), Bira, Sente, Taleus Sente (Sundanese)
Italian: Alocasia, Orecchio Di Elephante, Apé
Japanese: Dokuimo, Kuwazu-Imo, Indo Kuwazu Imo
Kapingamarangi: Ngaungau
Kosrae: Onak Owa, Onak Wed
Khmer: K’da:T Haôra
Lamotrek: File
Laotian: Kaph’uk
Latvian: Lielsakņu Alokāzija
Lesser Antilles: Giant Tayo
Malaysia: Birah Hitam, Birah Negeri, Keladi Sebaring, Daun Keladi (Leaf)
Marquesan: Kape
Marshallese: Majol Wot, Ot, Wat, Wot, Wõt
Murilo: Oht
Namoluk, ***Nomwin***: Ka
Namonweito: Oot
Nepali: Ghampe Tarul, Jate Tarul
New Caledonia: Aware, Ica, Ka’ait, Kape, Kaxete, Koe, Kowe, Moerere, Peka, Pia, Pidu, Pindu, Poare, Twowe, Wave
Niuean: Kape
Palauan: Bisech, Bisech Ra Belau
Papua New Guinea: Abir, Paragum, Pia, Via (Tok Pisin)
Philippines: Gabi, Talipan (Bikol), Badiang, Bagiang, Biga, Galiang, Ragiang, Taliang (Bisaya), Bilbila (Bontok), Aba (Ibanag), Bilan Mumpaha, Helan Mumpahag (Ifugao), Aba-Aba (Igorot), Bira, Sininaba (Iloko), Biga, Gandus (Pampangan), Badiang, Biga, Gabing San Fernando, Malabiga (Tagalog)
Pohnpeian: Cha, Oht, Sepwikin
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Puerto Rico: Yautía Cimarrona
Rarotongan: Kape
Samoan: Ta’amu
Satawalese: File
Spanish: Cará Tayá, Malanga
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Tahitian: Ape, ‘Ape
Thai: Kradatdam, Kradat, Kradat Daeng, Kra Dao, Hora
Tokelau: Ta’amu
Tongan: Kape

Turkish: Alokasye
Tuvalu: Ta'amu, Puluka
Ulithian: Fole
Vanuatu: Lese-En, Pia
Vietnamese: Hải Vu, Ráy, Ráy Voi, Hải Vu
Wallis & Futuna: Kape
Woleai: Fille
Yapese: File, Maching, Monuw, Lai, La'Iy

Origin/Distribution

Giant taro is native to tropical Asia – probably originated from India, Sri Lanka and Southeast Asia and spread to other Asian tropical countries and Oceania.

Agroecology

Giant taro is found in Sri Lanka, India, the Philippines and Malaysia where it grows in the forest understorey in openings, roadside ditches, margins of wet fields and along streams or cultivated at low and medium, 0–600 m altitudes. It has been reported to adapt best to areas with 1,700 mm rainfall uniformly distributed throughout the year (Kay 1973). It prefers moist, but well-drained soil that is rich in organic humus and will grow in medium to heavy soils and limestone soils that are well drained as it abhors water-logged conditions. It is moderately salt tolerant as it is found growing on many atolls in the South Pacific. Giant taro can tolerate shallow flooding. It is the most drought tolerant of all the edible aroids. It is a little more cold hardy than many of its relatives, tolerating temperatures down to 10 °C, but freezing temperatures damage the leaves but the trunk sprouts new ones (Kay 1973).

Edible Plant Parts and Uses

Swollen stems tubers and leaves of giant taro are edible. The underground corms and cormels are also used for food after thorough cooking, particularly in times of scarcity. The swollen stem tubers, corms and cormels are starchy and fibrous but are poisonous if eaten raw because it contains raphide oxalic acid crystals, causing the mouth and throat to swell, sometimes fatally. They require prolonged boiling or roasting before serving or processing as a food. They are cut into pieces and boiled in water and again in broth or coconut milk and is also fried in coconut or kenari (*Aleurites moluccana*) oil or curries and stews. In Papua New Guinea, the young leaves are cooked in coconut milk and eaten. The leaves may be eaten cooked (e.g. fried with onions, garlic, chilli, etc.). Giant taro is a source of easily digestible, white starch or flour.

Botany

Giant taro is a coarse, erect perennial monoecious, rhizomatous plant growing up to 5 m high with massive leaves borne on green succulent stout petioles 0.6–1.8 m long at the tipoff stems of larger plants (Plates 1, 2 and 3). The petioles emerge from a stout upright, elongated, erect, woody stem, 1–1.2 m long and 25 cm diameter (Plate 2), arising from a basal corm. The leaves

Plate 1 Giant taro plant habit

Plate 2 Giant taro stem

Plate 3 Exposed rhizome

are very large, glossy medium green, broadly sagittate, 0.9–1.8 m long by 0.6–1.2 m wide, with the margins slightly undulate; the apex pointed, and the base deeply cordate and prominent lateral venation. Inflorescences are relatively large and usually appear in clusters (2 to several) and are subtended by cataphylls. The upper part of the spathe is yellowish and membranous and forms an incomplete hood around the spadix and is deciduous or marcescent. The spadix has four

Plate 4 Immature inflorescences with dried spathes and fruits

parts, a lower pistillate zone, a sterile zone and the staminate zone top by a large sterile appendix. Pistillate zone conic–cylindrical, 1–2 cm by 1.5 cm across, female flowers are naked, globose, pale green ovaries and with button-like sessile three to five lobed, yellow stigma. The ovules are few and orthotropous. Sterile interstice slightly shorter or equal to female zone, whitish. Staminate zone cylindrical, 3–7 cm long by 2 cm across, whitish, male flowers consist of -5–9 merous rhomboid–hexagonal synandria. Fruiting spathe oblong–ellipsoid, 8 cm long, green. Fruits are several seeded ellipsoid or ovoid, green ripening to scarlet fleshy berries (Plate 4).

Nutritive/Medicinal Properties

Stem/Corm/Cormel: Nutrients/ Phytochemicals

The food nutrient value of the edible portion of the raw giant taro stem tubers had been reported as per 100 g edible portion: energy 100 cal (412 kJ), water 70 g, protein 2.2 g, fat 0.1 g, available carbohydrate 23 g, dietary fibre 1.9 g, Na 30 mg, K 267 mg, Ca 38 mg, Mg 52 mg, Fe 0.8 mg, Zn 1.6 mg, thiamine 0.02 mg, riboflavin 0.02 mg, niacin traces, vitamin C 17 mg and vitamin E 2 mg (Dignan et al. 1994). Kay (1973) reported the food value of the edible portion of the raw stem tubers of giant taro as energy 293–599 kJ/100 g, water 63–81 %, crude protein

0.6–3.3 %, fat 0.1–0.2 %, carbohydrate 17–27 %, ash 1.1–1.3 %, calcium 46–153 mg/100 g, iron 0.5–1 mg/100 g, phosphorus 45–72 mg/100 g, niacin 0.4 mg/100 g, riboflavin 0.02–0.03 mg/100 g, thiamine 0.09–0.1 mg/100 g and ascorbic acid trace. Much of the calcium is in calcium oxalate crystals. *Alocasia macrorrhiza* tubers were found to contain on a weight-to-weight basis 60.5 % neutral lipids, 19.0 % glycolipids and 20.5 % phospholipids, while the total extractable lipids accounted for 0.6 % of the dry weight (Opute and Osagie 1978). Additionally, the presence of tri- and tetragalactosyl diglycerides was confirmed. The predominant fatty acid in each lipid class was linoleic acid with palmitic, oleic and linolenic acids being the other ones. A high degree of unsaturation (66 %), similar for most tuber lipids, was established for the component fatty acids of *Alocasia*. Ferredoxin isoproteins (Fd A and Fd B) were isolated from *Alocasia macrorrhiza* (Wada et al. 1992). They consisted of single polypeptide chains of 97 and 98 residues, respectively, and both Fds had a molecular mass of 10,800 Da. There was an 88 % identity between the sequences of the isoproteins (Fd A and Fd B).

Tubers were found to contain sterols: cholesterol, β-sitosterol, stigmasterol, campesterol and fucosterol (Osagie 1977). Tubers contain a heat-labile amylase enzyme (Shivaraj et al. 1979), trypsin/chymotrypsin inhibitors (Sumanthi and Pattabiraman 1977; Hammer et al. 1989; Peng et al. 1993; Argall et al. 1994; Mathews et al. 1996) and a lectin AML (Zhu et al. 2006). A new ceramide alomacrorrhiza A was isolated from the ethanolic extract of the root and its structure elucidated as (2S,3S,4R)-2 N-[(2′R)-2′-hydroxyhexacosanoyl]-tetradecane-1,3,4-triol (Nguyen et al. 2004). Five new indole alkaloids, alocasins A–E, together with known hyrtiosin B and hyrtiosulawesin were isolated from *Alocasia macrorrhiza* rhizome (Zhu et al. 2012).

Major compounds identified in the ethanol extract of *A. indica* corm included: β-hydroxyque brachamine (1.9 % area), gibb-3ene-1,10-dicarboxylic acid,2,4 α-dihydroxy-1-methyl-8-methylene,14α-lactone,10methyl ester (3.8 %), 4,4-dithiobis butanoic acid (2.6 %), 5-(*p*-aminophenyl)-4-(*O*-tolyl)-2 thiazolamine (8.4 %), 3H-1,4-benzodiazepine-2-amine,7-chloro-N-methyl-5-phenyl,4-oxide (4.7 %), 10, 12, 14 nonacosatriynoic acid (15.3 %), androst-4-en-11-ol-3,17-dione,9-thiocyanato (16 %), estra-1,3,5(10)-trien-17-one,3-hydroxy-6-methoxy, *O*-methyloxime (29.5 %), 17 α-ethynyl-17 β-hydroxy-6-β-methoxy-3 α, 5 cyclo-5 α-androstan-19-oic acid (tr), 1H indole,3 benzyl -2-phenyl (tr) and 1H indole, 5 methyl-2,3-diphenyl (tr) (Pal et al. 2014a).

Alocasia indica starch, an almost white powder, was found to a mean grain diameter of 4.77 um, ash value 3.2 %, swelling factor of 10.63, viscosity (5 % w/v) of 8.16 and pH 8.1 and 9.4–9.8 % loss on drying (Lodha and Nemade 2012). *A. indica* starch in 10 % w/w tablet formulation was found to possess disintegrating property and could be useful in conventional tablet formulation. The disintegration time for tablet formulations prepared using 10 % w/w isolated starch was less (109 seconds) than that of the tablet formulations prepared using maize starch as a disintegrant (129 seconds).

Other Plant Parts: Phytochemicals

The plant was reported to contain oxalic acid (Srivastava and Krishnan 1959). Calcium oxalate crystals occur in the form of raphides, which are highly abundant in aroids (Araceae) such as taro (*Colocasia esculenta*), swamp taro (*Cyrtosperma chamissonis*) and elephant ear taro (*Alocasia macrorrhiza*) and yams (*Dioscorea esculenta*) (Loy et al. 1992; Crowther 2009). Loy et al. (1992) noted that the size, cross-section and termination shape of raphides produced by different species varied so as to be "seemingly distinctive … to genus". Raphide of *A. macrorrhiza* was described as elongate with pointed ends and square in cross-section. Four types of raphides were reported to be produced by higher plants based on sectional and termination shape and crystallographic characteristics, and giant taro was found to have type 4 raphides, twinned crystals with H-shaped cross-sections (because of middle groove) and asymmetrical ends sharp at one end and wedge shaped or blunt at the other end (Crowther 2009).

Young leaves contained the cyanogenic glycosides triglochinin (*O*-[β-D—glucopyranosyl]-1-cyano-1-hydroxy-2-methylcarboxy-carboxy-Δ-1,2(*E*)-Δ-3,4(*Z*)-butadiene) and isotriglochinin (*O*-[β-D—glucopyranosyl]-1-cyano-1- hydroxy-2-methylcarboxy-carboxy-Δ-1,2(*E*)-Δ-3,4(Z)-butadiene) (Nahrstedt 1975). Beta-glucosidases isolated from *Alocasia macrorrhiza* were found to be highly specific for the hydrolysis of the cyanogenic glucoside triglochinin endogenous to this plant (Hösel and Nahrstedt 1975). The main fractions possessed molecular weights of approximately 310,000 and 105,000, comprising subunits of molecular weight 55,000–60,000. The hexameric beta-glucosidase was shown to dissociate in dimers without any alteration of activity (Hösel and Klewitz 1977). They suggested it was possible that the different beta-glucosidases splitting triglochinin arose during purification from the hexameric form which occurred in the plant. The hydroalcoholic leaf extract of *Alocasia indica* was reported to contain flavonoids, cyanogenic glycosides, citric acid, ascorbic acid and polyphenolic compounds (Mulla et al. 2009a).

The spadix was reported to contain 16 free amino acids, appreciable amounts of citric and malic acids, ascorbic acid and traces of succinic acid and also glucose, fructose and sucrose (Joshi and Pandit 1956). A class of arabinogalactan proteins, β-lectins was isolated from the leaves and seeds (Clarke et al. 1978).

Antioxidant Activity

The hydroalcoholic leaf extract at 1,000 µg/mL showed maximum scavenging of superoxide radical (87.17) by riboflavin-NBT system, followed by scavenging of stable radical 1,1-diphenyl-2-picryl hydrazyl (DPPH) radical (83.48 %), nitric oxide radical (74.09 %) and hydroxyl radical (60.96 %) at the same concentration (Mulla et al. 2009b). However, the extract showed only moderate activity by iron chelation (68.26 %). The ethanolic leaf extract also showed remarkable antioxidant activity in-vitro antioxidant models of screening like scavenging of 1, 1-diphenyl-2-picryl hydrazyl (DPPH) radical, nitric oxide radical, superoxide anion radical and hydroxyl radical comparable to the standard reference drug ascorbic acid (Mulla et al. 2010a). The hexane, benzene, toluene, chloroform, diethyl ether, ethyl acetate and water fraction of *Alocasia macrorrhiza* plant parts exhibited DPPH antioxidant activity with IC_{50} values in the following order, roots > rhizome > leaves (Mandal et al. 2010). Maximum antioxidant activity was observed in diethyl ether extracts. The IC_{50} values were comparable with those of quercetin and ascorbic acid as standards. The methanol rhizome extract showed a dose-dependent moderate DPPH radical scavenging activity, and the maximum scavenging activity of 38.42 % was found at 500 µg/mL. The IC_{50} value of the extract was 693.0 µg/mL (Rahman et al. 2012). The extract exhibited mild reducing power activities compared to ascorbic acid. In DPPH radical scavenging assay, the ethanol tuber extract exhibited strong radical scavenging activity with the 50 % inhibitory concentration value of 42.66 µg/mL (Islam et al. 2013). Total phenolic content was found to be 542.26 mg gallic acid equivalent per 100 g of dried tuber extract, whereas flavonoid content was found to be 4.30 mg quercetin equivalent/g of dried tuber extract. In reducing power assay, the tuber extract showed strong reducing power in a concentration-dependent manner.

Antihyperglycaemic Activity

The methanol extract of *A. macrorrhizos* rhizome administered to alloxan-induced hyperglycaemic mice at 500 mg/kg produced a significant decrease in the blood glucose level (55.49 %) at 8 hours of treatment when compared with the control and was comparable with the reference drug, metformin (Rahman et al. 2012). Studies showed that streptozotocin-induced diabetic rats administered with graded doses (200 mg and 400 mg/kg) of *A. indica* leaf extract for 3 weeks elicited significant increase in body weight and decrease in blood glucose level and serum lipid profiles (cholesterol and triglyceride) in test extract-treated animals compared to diabetic control group (Patil et al. 2012).

Anticancer Activity

Aqueous extract of *A. macrorrhiza* exhibited inhibitory effect of 29.38 % against murine sarcoma S180 in mice and inhibitory effect of 51.72 % against transplantable human gastroadenitis (SGC-7901) in nude mice (Ke et al. 1999). No antitumour effect was shown against Ehrlich ascites carcinoma in mice. *A. macrorrhiza* root ethyl acetate extract exhibited antitumour effects in-vitro against human lung adenocarcinoma A549, murine melanoma B16 and human gastric adenocarcinoma BGC-823 cancer cell lines with IC_{50} values of 94.6, 541.9 and 629.5 µg/mL, respectively, and acetone extract against A549 and B16 cancer cell lines with IC_{50} values of 40.9 and 438.0 µg/m, respectively (Zhao 2008).

Indole alkaloids, isolated from the rhizome, hyrtiosulawesin and alocasins A, D and E, showed mild antiproliferative activity in-vitro against human throat cancer (Hep-2) and human hepatocarcinoma (Hep-G2) cell lines, while compounds hyrtiosulawesin and alocasin B showed weak antiproliferative activity against human nasopharyngeal carcinoma epithelial (CNE) cell line (Zhu et al. 2012). *Alocasia macrorrhiza* tuber aqueous extract exhibited proliferation inhibition and apoptosis effects on human hepatocellular carcinoma cells in-vitro and inhibited hepatoma growth in-vivo (Fang et al. 2012). The mechanism of its action was suggested to be associated with the inhibition of DNA synthesis, cell cycle (G(0)/G(1)) arrest, apoptosis induction through upregulation the mRNA and protein expressions of PPARγ, Rb, Bax and capase-3genes and downregulation of the expressions of cyclin D1 and Bcl-2 genes.

Cytotoxicity Activity

The methanol rhizome extract showed mild cytotoxicity with a LC_{50} value of 188.14 µg/mL as compared to vincristine sulfate, which served as the positive control with a LC_{50}value of 11.32 µg/mL in the brine shrimp lethality assay (Rahman et al. 2012). The petroleum ether and carbon tetrachloride-soluble fractions of the tuber methanol extract showed potent cytotoxicity activity with LC_{50} of 0.58 µg/mL and 0.50 µg.mL, respectively, in the brine shrimp *Artemia salina* lethality assay (Hoque et al. 2012).

Laxative and Diuretic Activities

The ethanolic leaf extract at 100, 200 and 400 mg/kg concentrations produced significant laxative, diuretic and natriuretic activity in rats (Mubeen et al. 2012).

Anti-inflammatory Activity

Oral administration of the ethanol dried rhizome extract to rats at doses of 300 and 600 mg/kg of body weight exerted a significant anti-inflammatory activity against carrageenan-induced paw oedema in rats which was comparable to the standard drug aspirin at the dose of 150 mg/kg of body weight (Rahman et al. 2011). The ethanolic leaf extract and gels produced dose-dependent activity in the carrageenan-induced paw oedema, formalin-induced paw oedema, arachidonic acid-induced ear oedema and xylene-induced ear oedema assays (Mulla et al. 2010a).

Analgesic Activity

The ethanolic leaf extract and gels produced dose-dependent antinociceptive activity when evaluated by the acetic acid-induced writhing response, hot-plate method and tail-flick method in albino rats (Mulla et al. 2010a). The ethanol dried rhizome extract showed significant writhing inhibition in acetic acid-induced writhing in mice at the oral dose of 300 and 600 mg/kg of body weight comparable to the standard drug diclofenac sodium at the dose of 25 mg/kg of body weight (Rahman et al. 2011).

Antimicrobial Activity

Bhatt and Saxena (1980) reported the seed extract exhibited antifungal activity in-vitro. Alocasin, an antifungal protein isolated from the rhizomes

of the giant taro, reduced the activity of HIV-1 reverse transcriptase (Wang and Ng 2003). Alocasin displayed antifungal activity against the fungus *Botrytis cinerea*. It exhibited weak haemagglutinating activity, only at a concentration of 1 mg/mL. The petroleum ether, chloroform, acetone, ethanol and water leaf extracts at 5 and 10 mg/mL doses showed significant in-vitro antibacterial and antifungal activity against bacteria *Bacillus subtilis*, *Staphylococcus aureus*, *Klebsiella pneumonia*, *Escherichia coli*, and fungi *Aspergillus niger*, *Candida albicans* and *Saccharomyces cerevisiae* (Mulla et al. 2010b). The ethanol extract was found to possess comparatively more potent antimicrobial activity with lower MIC (minimum inhibitory concentration) against the tested microorganisms. The methanol tuber extract and chloroform-soluble fraction showed growth inhibitory activity in-vitro against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Shigella boydii* and *Vibrio parahaemolyticus* (Hoque et al. 2012). The chloroform fraction also inhibited growth of *Bacillus subtilis*, *Sarcina lutea*, *Escherichia coli*, *Shigella dysenteriae* and *Vibrio mimicus*.

Hepatoprotective Activity

Oral administration of hydroalcoholic extract of *A. indica* (250 and 500 mg/kg) effectively inhibited CCl_4 and paracetamol-induced changes in the serum marker enzymes, cholesterol, serum protein and albumin in a dose-dependent manner as compared to the normal and the standard drug silymarin-treated groups (Mulla et al. 2009a). Hepatic steatosis, fatty infiltration, hydropic degeneration and necrosis observed in CCl_4 and paracetamol-treated groups were completely absent in histology of the liver sections of the animals treated with the extracts. *Alocasia macrorrhiza* leaf juice was found to possess hepatoprotective and antioxidative efficacy when tested in-vitro using rat liver slice model (Patil et al. 2011). *A. macrorrhiza* leaf extract decreased significantly the leakage of aminotransferase (AST), alanine aminotransferase (ALT) and alkaline phosphatase (ALP) into the surrounding incubation medium and prevented the depletion of total glutathione contents and build-up of TBARS induced by CCl_4 and Tylenol. Ethanolic extract of the corm also showed potent hepatoprotective activity against CCl4-induced hepatotoxicity in male albino Wistar rats (Pal et al. 2014a). The elevation in malondialdehyde (MDA) level in CCl4-treated animal which indicated lipid peroxidation in liver tissue was significantly reversed by the extract. In CCl4-treated group, there was a decrease in glutathione (GSH) level by 30.04 % compared to control group. Treatment with the ethanol corm extract at 200 mg/kg/day enhanced the GSH level by 55.46 %. CCl4 induced severe necrotic changes and substantial changes in liver which were ameliorated by the extract. Corm ethanol extract also exhibited antioxidant activity which was higher than the aqueous corm extract. For the ethanol corm extract, the IC_{50} values for DPPH radical scavenging was 1.31 mg/mL, hydroxyl radical scavenging 3.90 μg/mL, nitric oxide radical scavenging 13.97 mg/mL and super oxide radical scavenging 5.73 μg/mL. For the aqueous corm extract, IC_{50} values for DPPH radical scavenging was 3.32 mg/mL, hydroxyl radical scavenging 3.71 μg/mL, nitric oxide radical scavenging 19.95 mg/mL and super oxide radical scavenging 8.13 μg/mL. Both extract showed the presence of various phytochemical compounds, e.g. alkaloids, flavonoids, glycosides, saponin, tannins as well as superoxide dismutase (SOD) and catalase (CAT) enzyme activity. Ethanolic extract showed higher phenolic and flavonoid content than aqueous extract.

Intraperitoneal administration of the ethanolic extract of *A. indica* corm for 15 days significantly ameliorated the hepatotoxic effects induced by alcohol in rats (Pal et al. 2014b). The extract significantly and dose dependently reduced the marked elevation of liver biomarkers such as serum ALT, AST, γ-glutamyl transpeptidase (γ-GT) and total bilirubin levels. It also improved antioxidant status (MDA, nitric oxide and GSH) and preserved hepatic cell architecture. Simultaneous supplementation with the extract significantly restored hepatic CAT and SOD activity levels towards normal.

Antidiarrheal Activity

The aqueous and ethanol leaf extracts exhibited significant in-vitro antidiarrhoeal activity compared to the standard drug ciprofloxacin (10 µg/mL) as evaluated against *Escherichia coli*, *Salmonella typhimurium*, *Shigella flexneri* and *Staphylococcus aureus* by agar well diffusion method (Mulla et al. 2011). The aqueous and ethanol leaf extracts showed significant and dose-dependent antidiarrhoeal activity in-vivo comparable to that of the reference drug loperamide (10 mg/kg) against recinoleic acid-induced diarrhoea and magnesium sulfate-induced diarrhoea. The ethanol tuber extract significantly enhanced the latent period and decreased defecation in both castor oil- and magnesium sulfate-induced diarrhoea (Islam et al. 2013). The extract also lessened gastrointestinal motility in mice. Potential antibacterial activity was exhibited by the extract against all the tested bacterial strains in disc diffusion assay. The 50 % lethal concentration against brine shrimp nauplii was 81.09 µg/mL.

Haemagglutinating Activity

Alocasin exhibited weak haemagglutinating activity, only at a concentration of 1 mg/mL (Wang and Ng 2003).

Immunomodulatory Activity

Alocasia macrorrhiza lectin exhibited mitogenic activity on human peripheral blood lymphocytes at 50 µg/mL (Kamboj et al. 1995). The lectins were T-cell mitogens, and did not induce any appreciable DNA synthesis in B-enriched lymphocytes. The mitogenic response was shown to be inhibited by asialofetuin in a concentration-dependent manner.

Antiprotozoal Activity

The aqueous and ethanol leaf extracts exhibited significant in-vitro antiprotozoal activity against both protozoa *Entamoeba histolytica* and *Giardia intestinalis* compared to the standard amoebicidal and giardicidal drugs, metronidazole and emetine (Mulla et al. 2011).

Thrombolytic Activity

The methanol extract of *A. indica* tuber and petroleum ether and carbon tetrachloride-soluble fractions showed moderate clot lysis activity ranging from 45.61 to 20.51 % (Hoque et al. 2012). They showed significantly membrane stability activity and significantly protected lysis of human erythrocyte membrane induced by hypotonic solution and heat-induced haemolysis, as compared to the standard acetyl salicylic acid.

Antimalarial Activity

Alocasia macrorrhiza leaf extract (60–300 ppm) exhibited larvicidal activity against the first to fourth instar larvae of the *Anopheles stephensi*, the malarial vector, and caused pupal mortality of *A. stephensi* (Durga Devi and Murugan 2013). The LC_{50} and LC_{90} values were represented as follows: LC_{50} value of I instar was 126.55 ppm, II instar was 143.19 ppm, III instar was 165.10 ppm, and IV instar was 186.13 ppm. The LC_{90} value of I instar was 278.81 ppm, II instar was 327.47 ppm, III instar was 380.01 ppm, and IV instar was 421.04 ppm. The LC_{50} value of pupae was 205.68 ppm, and the LC_{90} value of pupae was 456.92 ppm.

Anthelminthic Activity

The hydroalcoholic leaf extract and its petroleum ether and ethyl acetate fractions were found to paralyse (vermifuge) and kill the test earthworm, *Pheretima posthuma* (vermicidal) (Mulla et al. 2010c). The 50 mg/mL dose was more effective as compared to the standard reference, piperazine citrate.

Antihyperlipidaemic Activity

The hydroalcoholic extract of *Alocasia macrorrhizos* leaves at the dose of 250 and 500 mg/kg in rats fed a cholesterol-rich high-fat diet for 45 days significantly reduced triglyceride and VLDL-C levels; however, it increased LDL-C, and hence may not be suitable as a lipid-lowering agent (Ramya et al. 2012).

Protease Inhibitory Activity

Trypsin/chymotrypsin inhibitors were isolated from *Alocasia macrorrhizos*. A trypsin/chymotrypsin inhibitor with molecular weight of about 3,200 was isolated from the tubers (Sumathi and Pattabiraman 1977). The inhibitor acted on bovine trypsin, human trypsin and bovine chymotrypsin. It had no action on human chymotrypsin, subtilisin BPN, pronase, *Aspergillus oryzae* protease and human and porcine pepsins. The trypsin inhibitors isolated from giant taro, taro and giant swam taro had molecular weight of 35,000–38,000 and was similar to the Kutniz family inhibitor (Hammer et al. 1989). The trypsin/chymotrypsin inhibitor in giant taro occurred as a dimer of two identical monomers each with slight polymorphism and could be an attractive candidate for conferring insect resistance in transgenic plants (Argall et al. 1994). It was found to have 184 amino acid sequence with molecular mass of 19,774 Da for the Met-24, Glu-50 form. Giant taro trypsin/chymotrypsin inhibitor was found to be more related to taro (*Colocasia esculenta*) than to that of giant swamp taro (*Cyrtosperma chamissonis*) (Peng et al. 1993). A full-length cDNA encoding the 206 amino acid open reading frame of a trypsin/chymotrypsin inhibitor abundant in the corms of giant taro (*Alocasia macrorrhiza*) was isolated (Mathews et al. 1996). The cDNA of *Alocasia macrorrhiza* lectin (AML) was cloned and found to have an amino acid length of 280 amino acids with relative molecular weight of 29.7 kD (Zhu et al. 2006). It exhibited similarity to other mannose-binding lectins and similar proteins from Araceae family. Two typical B-lectin domains and three mannose-binding motifs were found in the sequence of AML. They concluded that this newly cloned AML cDNA encoded for a mannose-binding lectin.

Miscellaneous Activity

Nayak et al. (2002) found that *Alocasia macrorrhiza* tuber protein in its pure or crude form could be used for the rapid isolation of two of the prominent alpha2-globulins, haptoglobin and alpha2-macroglobulin from human serum.

Toxicity Issues

Several cultivars of *A. macrorrhiza* had been reported to be cyanogenic; young leaves had been found to contain up to 0.018 % of hydrogen cyanide, but cyanogenic glycoside was not reported to be present in the corms or stems (Kay 1973). A case of poisoning due to ingestion of a giant taro root tuber was reported by Chan et al. (1995). The patient developed neurological (severe pain and numbness in the perioral area and throat) and gastrointestinal (nausea, vomiting, abdominal pain) symptoms immediately after eating the root tuber. The neurotoxin was reported to be similar to sapotoxin that found in *Alocasia odora*. Twenty-seven cases of *A. macrorrhiza* poisoning were reported in 12 females and 15 males from age 1.5 to 68 years by Lin et al. (1998). One patient had eye contact, another skin contact. In the 25 cases that consumed the plant leaf or tuber either raw or cooked, the primary symptom was injected sore throat, and the secondary symptom was numbness of the oral cavity. Some patients had salivation, dysphonia, abdominal pain, ulcers of the oral cavity, difficulty in swallowing, thoracodynia, chest tightness and swollen lips. The authors believed that the presence of sapotoxin alone was not sufficient to explain the injected swollen and ulcerative lesions and that presence of calcium oxalate in the whole plant could be responsible for inflammation of the oral cavity and mucous membranes. Tang et al. (2006) reported a case of crystalline

keratopathy in the cornea caused by *Alocasia macrorrhiza* based on the observation of needle-like crystals in the corneal stroma following injury to the eye. The condition resolved in 3 months with the disappearance of the crystals confirmed by follow-up confocal microscopy.

In-vivo studies showed that oral administration of *A. macrorrhiza extract* in a dose of 144.6 mg/kg/day for 20 days impacted on the hepatorenal function in mice (Helal et al. 2008). RBCs and Hb were significantly decreased after treatment period. Total protein, albumin and globulin were significantly decreased, while, aminotransferase (AST), alanine aminotransferase (ALT), lactate dehydrogenase (LDH), gamma-glutamyl transferase (GGT), urea, creatinine and total lipid and cholesterol were significantly increased after treatment and recovery period of 10 days. Histological changes in treated sections of the liver showed evidence of cellular degeneration, and necrosis and in kidney sections, tubular necrosis, glomerular shrinkage and atrophied glomerular tuft of capillaries were prominent. Mallory-stained sections in liver showed increased collagen fibres around congested central veins, blood sinusoids and portal areas. The changes which were observed after treatment disappeared after a recovery period of 20 days.

Traditional Medicinal Uses

Giant taro had been used in folkloric medicine in India, Bangladesh, Southeast Asia and Papua New Guinea (Burkill 1966; Nadkarni and Nadkarni 1982; Chopra et al. 1986; Arief Hariana 2006; Khare 2007; Stuart 2013). In Malaysia, the application of the acrid juice had been reported to give instant relief to stings of the giant nettle (*Laportea*). Sap from the petioles were used to treat cough. In Java, the chopped-up roots and leaves may be used as an application for pains in the joints and as rubefacient. In Papua New Guinea, young leaves and sap are used externally to treat headache. In India, the tuber/corm is used in the treatment of scorpion stings, disease of the abdomen and spleen and gout and rheumatism and as mild laxative, as diuretic and as anti-inflammatory agent; the leaf is traditionally used as astringent, styptic and antitumour agent, root and leaf as rubefacient and leaf and stem as a bath for skin disorders itch and burns. A poultice of fresh leaves is applied to relive pain from varicose veins and improve blood circulation, steam oiled leaves are applied for painful joints, and toasted and powdered leaves are used to hasten wound healing. In Indonesia, the tuber is used for treatment of influenza, fever, headache, diarrhoea, malaria, typhoid, rheumatism, pulmonary tuberculosis and tuberculous lymphadenopathy, abscesses, ringworms and venomous bites of snakes, insects and dogs. In Bangladesh, the plant is employed in the treatment of diabetes; stem juice applied to prevent oedema, pain and bleeding from cuts and wounds. Whole plant is used as a therapy for pus in the ears, jaundice and constipation. In the Philippines, the petioles are ground together, placed in a piece of cloth with live coals and used as an application to alleviate toothache. Giant taro is widely used in China for treating joint disorders, flu complication, headache, bleeding haemorrhoids, pulmonary tuberculosis, chronic bronchitis and appendicitis and is used as an anti-inflammatory (Ke et al. 1999). In Hawaii, the tuber is employed for the treatment of severe burns and acute abdominal pains (Kaaiakamanu and Akina 1922). In India, the tuber is traditionally used in the treatment of abdomen- and spleen-related disorder (Pal et al. 2014a).

Other Uses

Giant taro is widely planted as ornamental foliage plants in various landscape scenarios in gardens, parks and around buildings, hotels and resorts.

Crude *A. macrorrhiza* lectin (AML) was found to be toxic to larvae of cabbage butterfly (*Pieris rapae*), Asiatic corn borer (*Ostrinia furnacalis*) and tobacco cutworm (*Spodoptera litura*), acting mainly as stomach poison (Pan et al. 2007b). They also reported that four types of crude lectin extracted from *A. macrorrhiza* exhibited

toxic effects on four insect cell lines, namely, Sf-9 from *Spodoptera frugiperda*, Se301 from *Spodoptera exigua*, Hi5 from *Trichoplusia ni* and Hz from *Heliothis zea*; the relative cell death rates observed at 2 % crude extract were 91.40 %, 91.62 %, 97.13 % and 82.30 % respectively, after 24-hours treatment (Pan et al. 2007a). They also found that AML decreased the activities of amylase and protease of soybean aphid (*Aphis craccivora*), by binding and inhibiting these digestive enzymes of aphids, leading to nutrient deficiency, weakening the aphids and eventually leading to aphid mortality (Pan et al. 2010).

Studies showed that boiled leaves of the Giant taro could be a complete replacement for soybean meal in the diets of Mong Cai pig sows with only a slight increase in time to re-mating (from 7.2 to 12.7 days) and a reduction of 3.5 % in litter weight at weaning and providing threefold increase in economic benefits (Duyet 2010). The plant was formerly cultivated as pig feed in Brazil (Kay 1973). It has also been investigated as a potential raw material for the production of alcohol.

Comments

Alocasia macrorrhiza can be distinguished from *A. odora*; the latter has peltate leaves and proportionately much shorter spadix appendix (Boyce 2008). Further, *Alocasia macrorrhizos* never produce stolons from the base of the stems.

Giant taro is propagated from suckers, but shoot tips with a narrow part of the stem and rolled up young leaves, or sections of stem having two or three buds are also frequently employed.

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Amorphophallus paeoniifolius

Scientific Name

***Amorphophallus paeoniifolius* (Dennst.) Nicolson**

Synonyms

Amorphophallus campanulatus Decne., *Amorphophallus campanulatus* var. *blumei* Prain, *Amorphophallus campanulatus* f. *darnleyensis* F.M.Bailey, *Amorphophallus chatty* Andrews, *Amorphophallus decurrens* (Blanco) Kunth, *Amorphophallus dixenii* K.Larsen & S.S.Larsen, *Amorphophallus dubius* Blume, *Amorphophallus giganteus* Blume (illeg.), *Amorphophallus gigantiflorus* Hayata, *Amorphophallus malaccensis* Ridl., *Amorphophallus microappendiculatus* Engl., *Amorphophallus paeoniifolius* var. *campanulatus* (Decne.) Sivad., *Amorphophallus rex* Prain, *Amorphophallus rex* Prain ex Hook. f., *Amorphophallus sativus* Blume, *Amorphophallus virosus* N.E.Br., *Arum campanulatum* Roxb. (illeg.), *Arum decurrens* Blanco, *Arum phalliferum* Oken, *Arum rumphii* Gaudich. (illeg.), *Arum rumphii* Oken, *Candarum hookeri* Schott (illeg.)

Candarum roxburghii Schott (illeg.), *Candarum rumphii* Schott (illeg.), *Conophallus giganteus* Schott ex Miq. (illeg.), *Conophallus sativus* (Blume) Schott, *Dracontium paeoniifolium* Dennst., *Dracontium polyphyllum* Dennst. (illeg.), *Dracontium polyphyllum* G.Forst., *Hydrosme gigantiflora* (Hayata) S.S.Ying, *Kunda verrucosa* Raf. (illeg.), *Plesmonium nobile* Schott, *Pythion campanulatum* Mart.

Family

Araceae

Common/English Names

Cheeky Yam, Corpse Flower, Corpse Plant, Elephant Foot Yam, Elephant Yam, Stink Lily, Telinga Potato, Voodoo Lily, White-Spot Giant Arum,

Vernacular Names

Arabic: Batata El-Feel
Bangladesh: Ol
Brazil: Inhame Gigante, Toyoeu (Portuguese)
Burmese: Wa
Chinese: Bai Ban Mo, Bai Ban Mo Yu
Czech: Zmijovec Zvonovitý
Danish: Elefantyams
Fijian: Daiga, Vaaga, Via Gaga, Viamiloa
Flemish: Olifantspoot
French: Kouniak D'annam, Pomme De Terre De Télinga
Greek: Elephantini Dioscorea
Guyana: Hig Tannia
Hebrew: Amorpha

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India: Ol, Ol Kochu (Assamese), Shuran, Ole (Bengali), Suran (Gujarati), Alu, Jangli Suran, Kanda, Madana Masta, Zaminkand, Suran-Kand, Gandira, Zamin-Kand (Hindu), Choorana; Choorna Gedde, Gandira, Kanda Gedde, Panjaragedde, Soorana Gedde, Suvarna-Gadde, Suvarna Gedda, Suvarna Gedde, Suvarna-Guddab, Suvarna Gedde (Kannada), Soorna, Suma (Konkani), Haopan (Manipuri), Suran (Marathi), Cena, Mulenschena, Schena, Karunakarang, Kizhanna, Cinapavu (Malayalam), Farasi, Olua, Owa, Samba, Simba (Oriya), Jimikand, Zimikand (Panjabi), Suranah, Alu, Arsaghna, Arshoghna, Arsoghna, Bahukanda, Durnamari, Kanda, Kandala, Kandanayaka, Kandarha, Kandashurana, Kandi, Kandula, Kandvardhana, Kanthalla, Kunda, Ola, Olla, Rutchyakanda, Sala, Sthulakandaka, Sukandi, Surana, Suranah, Suranaka, Suranakanda, Suvitra, Tivrakantha, Vajrakanda, Vajrandi, Vatari (Sanskrit), Karakarunai, Karnai Kilangu Karakarunai, Karnai Kilangu, Karunaikkalang, Karunaikkilhangu, Karak Karunai, Karikkarunai, Anaittantu, Karukkarunaikkilangu, Karunai-K-Kilanku, Karunai-T-Tantu, Karakarunai, Karunai Kizhangu, Karakkaranai, Karuna Kalang, Karak-Karunai, Senai Kizhangu, Boomi Sallaraikilangu, Karunaikkishangu, Kiccilikkizanku, Camattilai, Cenai, Cirramitakkarunai, Curanam, Kantai, Karanai, Karunai, Karunaippala, Malaiyalaccenaikkilanku, Perunkarunai, Pulikkarunai, Taittiyamatanacceti, Taittiyamatanam (Tamil), Daradakandagadda, Ghemikanda, Kanda, Kandagodda, Manchi-Kindaguddae, Manchikanda, Poti-Kunda, Potikanda, Thiya-Kandha, Manchi Kanda (Telugu), Parinki Gadde, Pariṅkigaḍḍè, Sūraṇa (Tulu), Hati Yam, Jangli Suran, Zaminqand (Urdu)

Indonesia: Badur, Suweg, Iles-Iles, Kembang Bangah, Kembang Bangke, Sobek, Walur (Javanese), Ileus, Achung (Sundanese)

Japanese: Konjac, Konniaku

Khmer: Toal

Kiribati: Babai'

Laos: Duk Düa, Houo Ka Bouk, Kabuki

Malaysia: Hakai (Sakai), Loki, Lokai, Ubi Kekek

Marquesan: Teve

Nepali: Wol

New Caledonia: Pindu

Niuean: Teve

Persian: Zamin-Kand, Zaminkand

Philippines: Alu Pahi, Bagong (Bikol), Anto, Oroi, Pamangkilon (Bisaya), Bagang (Ibanag), Bagong (Sulu), Tigi-Nga-Magmanto (Iloko), Tokod-Banua (Pampangan), Apon, Apong-Apong, Pungapung (Tagalog)

Polish: Dziwidło Dzwonkowate

Portuguese: Jararaca Mirim, Batata De Telinga

Rarotongan: Teve

Samoan: Talanu, Teve

Spanish: Patata De Telinga

Sri Lanka: Kidaran

Tajik: Batat, Kartoshkai Shirin

Thai: Buk Khang, Man-Suran, Ukkhungkhok

Tongan: Teve

Turkish: Amorfotallus

Tuvalu: Puluka

Vietnam: Khoai Nưa, Nưa Chuông

Origin/Distribution

The species is native to tropical Asia. It grows wild in Sri Lanka, the Philippines, Malaysia, Indonesia and other Southeast Asian countries. It is also found in India, southern China, New Guinea, Northern Australia and Polynesia.

Agroecology

The plant is a tropical crop and requires an average temperature of 25–35 °C during its growth period. In its native range, it occurs in almost all imaginable secondary conditions, either secondary forest, coastal monsoon forests and thickets or highly disturbed areas and in dappled shade or fully exposed areas, from sea level to 700 m altitude. It prefers evenly distributed rainfall between 1,000 and 1,500 mm per annum, although the plant can be grown with rainfall as low as 650 mm provided irrigation facilities are available. Warm humid conditions favour leaf growth, and dry conditions favour the development of the corms.

Elephant yam prefers friable, deep loamy non-alkaline soil. It is hardy in tropical areas when planted in rich, well-drained soil in a sheltered, humid position. It does best in partial shade. It succumbs to waterlogging and heavy clayey soil; hence, good drainage is essential.

Edible Plant Parts and Uses

Tubers eaten after thorough cooking in *sayur* or as a titbit, sliced, baked or boiled especially in Indonesia (Ochse and Bakhuizen van den Brink 1980). Very young shoots still in the bud are used as vegetables in Indonesia. Leaves are also used as a tobacco substitute. Young petioles of young unexpanded leaves are edible when thoroughly cooked and considered a delicacy in the Philippines (Burkill 1966; Stuart 2014). In Malaysia, the indigenous Sakai eat the tubers after pounding and prolonged cooking. Starch from the tuber is used as food for diabetic persons, and the petiole is soaked in water and cooked in Vietnam (Tanaka and Nguyen 2007). The tuber may be used as a source of starch and alcohol and have been used to prepare a flour for bread-making. In India, the corm is prepared in curries, fried or used as pickles and chutney, while the above-ground parts are also eaten as green vegetable (Wikipedia 2014).

Studies found that Chinese noodles made from a blend of wheat flour and 3 % konjac glucomannan (KGM) were relatively desirable in textural properties and scored best in sensory evaluation, indicating the potential for improving textural defect of noodles prepared from low-protein wheat flour by using KGM (Zhou et al. 2013).

Botany

Stout herbaceous plant grows annually from a perennial subterranean corm to a height of 1.5 m (Plate 1). Corm is depressed-globose, to about 30 cm in diameter, about 20 cm high, dark brown, with distinct annular root scars (Plate 4). The pustular surface of the stem is attractively blotched with paler shades of green (Plate 2). Leaf usually solitary divided into

Plate 1 Elephant yam plant habit

Plate 2 Elephant yam blotched stem

Plate 3 Elephant yam leaves

Plate 5 Elephant yam inflorescence

Plate 4 Elephant yam corm

three major segments, which is further subdivided into oval or elliptic lobes about 6 cm long, leaf stalk up to 1 m or more, background colour pale to dark green with large and small pale blotches and numerous tiny dark dots (Plate 3). Inflorescence: flowers small, yellowish crowded into a stout column (spadix), male above and female below; the column is crowned by a reddish-brown bladderlike appendage, and the whole inflorescence is subtended by a large red brown bract (Plate 5). Fruit red, obovoid berry crowded on the spadix, 1.5 cm diameter, two to three seeded.

Nutritive/Medicinal Properties

The tuber of *Amorphophallus paeoniifolius* had been reported to have the following food value per 100 g edible portion (Brand-Millet et al. 1993): energy 70 kJ, moisture 79 g, nitrogen 0.24 g, protein 1.5 g, fat 0.3 g, ash 1.1 g, available carbohydrate 0 g, total dietary fibre 4.2 g, Ca 85 mg, Mg 33 mg, Fe 2,3 mg, Cu 0.1 mg, Na 3 mg, Zn 0.9 mg, niacin (derived from tryptophan or protein) 0.3 mg, niacin equivalents 0.3 mg and vitamin C 6 mg.

Analysis conducted in Indonesia reported that Suweg tuber flour had high content of dietary fibre (13.71 %) and protein (7.20 %) but had low fat content (0.28 %) (Faridah 2005). Suweg tuber had low glycaemic index (GI) of 42 with low starch in-vitro digestibility (61.75 %); hence, Suweg is categorised as a food product with low GI (<55).

The following compounds betulinic acid, triacontane, lupeol, stigmasterol, β-sitosterol and its palmitate were isolated from the plant (Chawla and Chibber 1976). Glucose, galactose (larger amount), rhamnose and xylose were also found as free sugars. The corm was reported to contain alkaloids, steroids, fats, fixed oil, flavonoids, tannins, proteins and carbohydrates (De et al. 2010b; Dey and Ghosh 2010b). The flavonoid content of the methanol and hydroalcoholic extracts of

A. paeoniifolius corms were found to be 46.33 and 36.88 mg/g rutin, respectively (Nataraj et al. 2009a). Similarly total phenolic content of the extracts (ME and AE) were found to be 12.67 and 6.25 mg/g catechol equivalent, respectively. The triterpenoid amblyone was isolated from *Amorphophallus campanulatus* tuberous root (Khan et al. 2008). A water-soluble polysaccharide isolated from the aqueous extract of *Amorphophallus campanulatus* corm was found to contain D-galactose, D-glucose, 4-*O*-acyl-D-methyl galacturonate and L-arabinose in a molar ratio of 2:1:1:1 (Das et al. 2009a). A polysaccharide konjac glucomannan with molecular weight of 115×10^6 daltons and moisture uptake of was found to consist of mannose and glucose units in the ratio of 1:0.13 (Nguyen et al. 2009, 2010). Water-soluble *O*-carboxymethyl glucomannan derivatives (*O*-CMG) with different degrees of substitution were synthesised successfully by reaction of a konjac glucomannan (isolated from the tubers of *Amorphophallus paeoniifolius*, one of the most abundant *Amorphophallus* species in Vietnam forest) directly with monochloroacetic acid (Nguyen et al. 2011).

Resistant starch III was prepared from elephant foot yam starch using pullulanase enzyme (Reddy et al. 2014). The enzymatic and retrogradation process increased the yield of resistant starch III from starch with a concomitant increase in its water absorption capacity and water solubility index. A decrease in swelling power was observed due to the hydrolysis and thermal process. The reduced pasting properties and hardness of resistant starch III were associated with the disintegration of starch granules due to the thermal process.

Antioxidant Activity

The methanolic and aqueous extracts of *Amorphophallus campanulatus* corm exhibited antioxidant activity in different in-vitro models, namely, 1, 1-diphenyl-2-picryl hydrazyl (DPPH) method, nitric oxide method and reducing power methods (Sahu et al. 2009). The extracts showed good dose-dependant free radical scavenging property in all the models. IC50 values for water and methanolic extract were found to be 59.91 and 99.40 µg/mL in DPPH method and 77.02 and 70.20 µg/mL in nitric oxide method. In reducing power method, the aqueous extract showed more reducing power compared to the methanolic extract.

Hepatoprotective Activity

Amorphophallus campanulatus corm exhibited potent hepatoprotective action against carbon tetrachloride-induced hepatic damage in rats (Jain et al. 2009). The ethanolic extract exhibited more potent hepatoprotective effects than the aqueous extract. The study suggested that possible mechanism of this hepatoprotective activity may be due to free radical scavenging potential caused by the presence of flavonoids in the extracts.

In-vitro and in-vivo studies revealed that the methanolic extract of *A. campanulatus* corm (ACME) had higher antioxidant and radical scavenging activity than the n-hexane extract which may be attributed to its higher phenolic and flavonoid content (Ansil et al. 2011). Methanolic extract of *A. campanulatus* (AMCE) corm significantly reversed the elevation of serum alanine transaminase (ALT) and aspartate transaminase (AST), alkaline phosphatase (ALP), lactate dehydrogenase (LDH) and tissue malondialdehyde levels induced by thioacetamide oxidative stress in male Wistar rats (Ansil et al. 2011, 2012). Hepatic and renal reduced glutathione (GSH), glutathione-S-transferase (GST), glutathione reductase (GR), glutathione peroxidase (GPx) and catalase levels were remarkably increased by the treatment with the extract. Quantification of histopathological changes also supported the dose-dependent curative effects of ACME.

Pretreatment of the rats with methanol and aqueous extracts of *A. paeoniifolius* corms prior to paracetamol administration caused a significant

reduction in the values of serum glutamic oxaloacetic transaminase (GOT), glutamic pyruvic transaminase (GPT), ALP and bilirubin almost comparable to the standard hepatoprotective agents silymarin and Liv-52 (Hurkadale et al. 2012). The hepatoprotective was confirmed by histopathological examination of the liver tissue of control and treated animals. In a recent study, administration of ethanolic extract of *A. campanulatus* at 250 and 500 mg/kg body wt significantly normalised the values of SOD, CAT, GSH and TBARS in rats with hepatotoxicity induced by ethanol (Datta 2013). The elevated serum enzymatic levels of AST, ALT, ALP and total protein were significantly restored towards normal by pretreatment with ethanolic extract of *A. campanulatus*. Histopathological studies also confirmed the hepatoprotective nature of the extracts by normalising the hepatocellular architecture in the extract-treated groups when compared to the only ethanol-administered group.

Quercetin isolated from *A. paeoniifolius* corm ethyl acetate fraction was found to have hepatoprotective effect on CCl_4-induced hepatotoxicity in rats (Sharstry et al. 2010). The extract reduced the CCl_4 elevated SGPT, SGOT and bilirubin enzymes levels, increased protein levels and attenuated the damaged hepatocytes towards normal architecture. The results were further supported by histopathology of isolated rat liver.

Anticancer/Cytotoxicity Activity

Amorphophallus paeoniifolius corm extract exhibited antiproliferative activity using *Allium cepa* root tip cell assay and Hep-2 cells (Angayarkanni et al. 2007). The corm petroleum ether and ethanol extracts showed low mitotic index 0.34 but high cytolytic index 75 % and 80 %, respectively. Of seven extracts tested, only petroleum ether and ethanol extracts displayed dose-dependent antiproliferative activity on Hep-2 cells. The terpenoid amblyone isolated from *A. campanulatus* exhibited moderate cytotoxicity against brine shrimp nauplii (Khan et al. 2008). In the cytotoxicity determination, LC_{50} of the compound against brine shrimp nauplii was 13.25 µg/mL. The ethanol extract of A. *paeoniifolius* corm exhibited antioxidant and antitumour activity against7,12-dimethylbenz(a)anthracene(DMBA)-induced mammary tumour in rats (Jagadheesh et al. 2010). The extract contained 8.8 g/100 g quercetin equivalent of flavonoids and exhibited significant antioxidant in scavenging DPPH and ABTS radicals in comparison to quercetin.

The subfractions of *A. campanulatus* tuber methanolic extract (ACME) viz. petroleum ether fraction (PEF), chloroform fraction (CHF), ethyl acetate fraction (EAF) and methanolic fraction (MEF) the subfractions of *A. campanulatus* tuber methanolic extract (ACME) viz. petroleum ether fraction (PEF), chloroform fraction (CHF), ethyl acetate fraction (EAF) and methanolic fraction (MEF) significantly inhibited the proliferation of colon cancer cell line, HCT-15 in a dose-dependent manner (Ansil et al. 2014). In addition, the extracts were found to induce apoptosis results suggested that, among the sub fractions of ACME, CHF had potent cytotoxic and apoptotic activity. *Amorphophallus campanulatus* tuber methanolic extract (ACME) exerted significant chemopreventive effect on 1, 2-dimethylhydrazine (DMH)-induced colon carcinogenesis in rats (Ansil et al. 2013). Supplementation of ACME significantly improved colonic MDA (malondialdehyde) and reduced glutathione levels and the activities of antioxidant enzymes in DMH-intoxicated rats. ACME administration also significantly suppressed the formation and multiplicity of aberrant crypt foci.

Antimicrobial Activity

The terpenoid amblyone isolated from *A. campanulatus* exhibited good antibacterial activity against four Gram-positive bacteria (*Bacillus subtilis*, *Bacillus megaterium*, *Staphylococcus aureus* and *Streptococcus pyogenes*) and six Gram-negative bacteria (*Escherichia coli*, *Shigella dysenteriae*, *Shigella sonnei*, *Shigella flexneri*, *Pseudomonas aeruginosa* and *Salmonella typhi*) but insignificant antifungal activity against *Aspergillus flavus*, *Aspergillus niger*, *Rhizopus oryzae* and *Candida albicans* (Khan et al. 2008).

The MIC values against the bacteria ranged from 8 to 64 μg/mL. The ability of mannans, especially konjac glucomannans, to prevent specific pathogens including *Escherichia coli* from adhering to the gut or bladder mucosa was highlighted by Tester and Al-Ghazzewi (2013).

Amorphophallus campanulatus leaf extract at levels greater than 4.5 mg/mL of 20 g/100 mL extract completely inhibited aflatoxin production by *Aspergillus flavus*, and suppression in growth was also well pronounced (81 % at 8.0 mg/mL) (Prasad et al. 1994). The comparative efficacy of the corm extract was lower. Calcium oxalate, an important constituent of the leaf, completely checked the growth and toxin biosynthesis at 0.4 mg/mL concentration.

Anti-inflammatory Activity

Methanol extract of *A. paeoniifolius* corm exhibited marked anti-inflammatory in carrageenan-induced paw oedema in rats, while the chloroform extract exhibited milder activity (De et al. 2010a). The methanol extract also exhibited antihistaminic effect in guinea pigs.

Antihyperglycemic Activity

The methanol extract of *A. campanulatus*, when administered to mice at doses of 50, 100, 200 and 400 mg per kg body weight, dose dependently reduced blood glucose levels in glucose-loaded mice, by 28.8, 29.1, 35.3, and 37.4 %, respectively (Rahaman et al. 2014). A standard antihyperglycaemic drug, glibenclamide, when administered at a dose of 10 mg per kg body weight, reduced blood glucose level by 40.7 %. Thus, the extract, at the highest dose tested, showed a near equivalent antihyperglycaemic potency to that of glibenclamide.

CNS-Depressant Activity

The petroleum ether extracts of *Amorphophallus paeoniifolius* corm at the dose levels of 100, 300 and 1,000 mg/kg body weight administered intraperitoneally into Swiss albino mice exhibited significant reduction in locomotor activity and in grip of the rotating rod, in a dose-dependent manner (Das et al. 2009b). The petroleum ether extract of *A. paeoniifolius* was found to have CNS depressant activity (Dey et al. 2011). A significant synergistic effect of the petroleum ether extract with diazepam was found, whereas there was little synergistic effect with phenobarbitone.

Analgesic/Antinociceptive Activity

The methanol extract of *A. campanulatus* corm when administered to mice at doses of 50, 100, 200 and 400 mg per kg body weight reduced the number of abdominal constrictions induced by intraperitoneal administration of acetic acid in mice by 30.4, 33.3, 42.4, and 45.5 %, respectively (Rahaman et al. 2014). In contrast, a standard antinociceptive drug, aspirin, when administered to mice at doses of 200 and 400 mg per kg body weight reduced the number of abdominal constrictions by 27.3 and 36.4 %, respectively, demonstrating that the extract, even at the lowest dose, was more potent than the lower dose of aspirin. The methanol extract of *A. campanulatus* tuber, given orally at the doses of 250 and 500 mg/kg, showed significant analgesic activity in mice (Shilpi et al. 2005). Intraperitoneal administration of the methanol corm extract of *A. paeoniifolius* (250–500 mg/kg body weight) in mice exerted analgesic activity in the tail flick and acetic acid-induced writhing response tests in a dose-dependent manner (Dey and Ghosh 2010a). The plant was suggested to have compounds that inhibited cyclooxygenase enzyme or acted on central opioid receptors.

Anxiolytic Activity

The petroleum ether extract of *Amorphophallus paeoniifolius* corm showed potent anxiolytic activity at a dose-dependent manner in mice in the elevated plus maze and open field test (Saha et al. 2013). The extract however failed to show any significant anxiolytic activity in light and dark test.

Tyrosinase Activity

Tyrosinase and laccase activities were detected in *Amorphophallus campanulatus* corm (Paranjpe et al. 2003). Tyrosinase was found to be the predominant enzyme exhibiting mono- and diphenolase activities, specificity for L-DOPA as substrate, optimum pH being 6.0, optimum temperature at 40 °C and Km at 1.05 mM. Three isoforms of tyrosinase were detected with apparent molecular mass approximately 127, 31 and 27 kDa, respectively. Tyrosinase was detected in the intercellular spaces of the plant tissue but not in the cytosolic region. Laccase showed substrate specificity for *p*-phenylenediamine (*p*-PD), Km at 2.7 mM, optimum pH being 5.0 and was inactivated above 40 °C. Tyrosinase from *Amorphophallus campanulatus* was immobilised on eggshell membrane using glutaraldehyde (Tembe et al. 2008). Studies on effect of pH showed retention of more than 90 % activity over a pH range 5.0–6.5. Membrane bound enzyme exhibited consistent activity in the temperature range 20–45 °C. Shelf life of immobilised tyrosinase system was found to be more than 6 months when stored in phosphate buffer at 4 °C.

Enzyme Inhibitory Activity

Amorphophallus campanulatus tubers exhibited antiprotease activity (Prathibha et al. 1995). When tubers were processed by pressure cooking, a partial retention of inhibition was observed in the case of trypsin inhibitor in *Amorphophallus*.

Immunomodulatory Activity

A water-soluble polysaccharide isolated from the aqueous extract of *Amorphophallus campanulatus* corm showed splenocyte activation (Das et al. 2009a). The methanol extract of *A. campanulatus* corm exhibited immunomodulatory activity by causing a significant decrease in charcoal clearance, spleen index and delayed-type hypersensitivity (DTH) response to sheep red blood cell (RBC) in sensitised mice (Tripathi et al. 2010).

Antidiarrhoeal Activity

Administration of the ethanolic extract of the *A. paeoniifolius* leaves, at the doses of 100, 200 and 400 mg/kg, significantly reduced the total number of faeces as well as diarrhoeic faeces in a dose-dependent manner in Swiss albino rats with castor oil-induced diarrhoea (Purwal et al. 2011).

Gastrotherapeutic Activity

The glucomannans including konjac glucomannans could be candidates for use as possible therapeutic tools for the treatment of a range of physiological disorders such as diverticulitis, Crohn's disease or ulcerative colitis (Tester and Al-Ghazzewi 2013).

Anticonvulsant Activity

Petroleum ether extracts of *A. paeoniifolius* showed dose-dependent anticonvulsant activity regarding onset of convulsion induced by isoniazid in mice (De et al. 2012)

Anthelmintic Activity

The methanol extract of *A. paeoniifolius* corm exhibited significant anthelmintic activity against *Pheretima posthuma* and *Tubifex tubifex* at highest concentration of 100 mg/mL (Dey and Ghosh 2010a). The extracts were found not only to paralyse (vermifuge) but also to kill the earthworms (vermicide). The chloroform, methanol extracts (containing tannins) and crude tannins showed very good anthelmintic activity against *Pheretima posthuma* (Ramalingam et al. 2010). Paralysis and death times were very close to the standard drug Albendazole.

Traditional Medicinal Uses

In Indian traditional medicine, the tubers are used as appetiser, aphrodisiac, expectorant, irritant and anti-catarrhal and for liver complaints, tumours, inflammation, haemorrhoids, vomiting, cough, bronchitis, asthma,, piles, abdominal pains, dyspepsia and acute rheumatism and for treating spleen enlargement (Chopra et al. 1986; Khare 2007) . The corm is deemed as carminative, restorative, stomachic and tonic. It is dried and used in the treatment of piles and dysentery. In Sri Lanka the corm is used for dropsy, urinary diseases, dyspepsia, toothache, rheumatism, boils, fistula, colitis, haemorrhoids, diuretic, piles, elephantiasis and glandular swellings. The tuber is widely used in South India as folk medicine to treat acute rheumatism, tumours, lung swelling, asthma, vomiting and abdominal pain (Angayarkanni et al. 2007). Traditionally, *Amorphophallus campanulatus* tuber is used for the treatment of enlarged spleen, rheumatism and tumour in India (Tripathi et al. 2010). *Amorphophallus paeoniifolius* was one of seven plant species that was found to be most important and frequently used by traditional healers in Palakkad district of Kerala, India, for dermatological infections/diseases and gastrointestinal disorders (Yabesh et al. 2014). Leaves were the most frequently used plant parts, and most of the medicines were prepared in the form of paste and administrated orally. In the Philippines, tubers (corms) are used for treatment of boils and haemorrhoids and poultices used as antirheumatic (Stuart 2014).

Other Uses

The tubers are sliced, sun-dried, pounded to a meal, boiled and fed to pigs, while the older petioles are boiled and used as pig food in the Philippines (Burkill 1966).

Comments

The fresh inflorescence emits an odour reminiscent of rotting meat which attracts pollinating carrion flies and beetles.

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Colocasia esculenta

Scientific Name

Colocasia esculenta **(L.) Schott**

Synonyms

Alocasia dussii Dammer, *Alocasia illustris* W. Bull, *Aron colocasium* (L.) St.-Lag., *Arum chinense* L., *Arum colocasia* L., *Arum colocasioides* Desf., *Arum esculentum* L., *Arum lividum* Salisb., *Arum nymphaeifolium* (Vent.) Roxb., *Arum peltatum* Lam., *Caladium acre* R.Br., *Caladium colocasia* (L.) W. Wight (illeg.), *Caladium colocasioides* (Desf.) Brongn., *Caladium esculentum* (L.) Vent., *Caladium glycyrrhizum* Fraser, *Caladium nymphaeifolium* Vent., *Caladium violaceum* Desf., *Caladium violaceum* Engl., *Calla gaby* Blanco, *Calla virosa* Roxb., *Colocasia acris* (R.Br.) Schott, *Colocasia aegyptiaca* Samp., *Colocasia antiquorum* Schott, *Colocasia antiquorum* var. *acris* (R.Br.) Schott, *Colocasia antiquorum* f. *acuatica* Makino, *Colocasia antiquorum* var. *aquatilis* (Hassk.) Engl. & K. Krause, *Colocasia antiquorum* f. *eguimo* Makino, *Colocasia antiquorum* var. *euchlora* (K. Koch & Linden) Schott, *Colocasia antiquorum* var. *fontanesii* (Schott) Schott, *Colocasia antiquorum* var. *globulifera* Engl. & K. Krause, *Colocasia antiquorum* var. *illustris* (W. Bull) Engl., *Colocasia antiquorum* var. *multifolia* Makino, *Colocasia antiquorum* var. *nymphaeifolia* (Vent.) Engl., *Colocasia antiquorum* f. *oyasetage* Makino, *Colocasia antiquorum* var. *patens* Makino, *Colocasia antiquorum* f. *purpurea* Makino, *Colocasia antiquorum* var. *rosea* Makino, *Colocasia antiquorum* var. *rupicola* Haines, *Colocasia antiquorum* var. *stolonifera* Haines, *Colocasia antiquorum* f. *yamamotoi* Makino, *Colocasia colocasia* (L.) Huth (inval.), *Colocasia esculenta* var. *acris* (R.Br.) A.F. Hill, *Colocasia esculenta* var. *antiquorum* (Schott) F.T. Hubb. & Rehder, *Colocasia esculenta* var. *aquatilis* Hassk., *Colocasia esculenta* f. *ebiimo* Makino, *Colocasia esculenta* var. *euchlora* (K. Koch & Linden) A.F. Hill, *Colocasia esculenta* var. *fontanesii* (Schott) A.F. Hill, *Colocasia esculenta* var. *globulifera* (Engl. & K. Krause) R.A. Young, *Colocasia esculenta* var. *illustris* (W. Bull) A.F. Hill, *Colocasia esculenta* var. *nymphaeifolia* (Kunth) A.F. Hill, *Colocasia esculenta* f. *rotundifolia* Makino, *Colocasia esculenta* var. *rupicola* (Haines) H.B. Naithani, *Colocasia esculenta* var. *stolonifera* (Haines) H.B. Naithani, *Colocasia euchlora* K. Koch & Linden, *Colocasia fontanesii* Schott, *Colocasia gracilis* Engl., *Colocasia himalensis* Royle, *Colocasia neocaledonica* Van Houtte, *Colocasia nymphaeifolia* (Vent.) Kunth, *Colocasia peltata* (Lam.) Samp., *Colocasia tonoimo* Nakai, *Colocasia vera* Hassk., *Colocasia violacea* (Desf.) auct., *Colocasia virosa* (Roxb.) Kunth, *Colocasia vulgaris* Raf., *Leucocasia esculenta* (L.) Nakai, *Steudnera virosa* (Roxb.) Prain, *Zantedeschia virosa* (Roxb.) K. Koch

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Family

Araceae

Common/English Names

Chinese Potato, Cocoyam, Colocasia, Curcas, Dalo, Dasheen, Dry Taro, Eddoe, Egyptian Colocasia, Elephant Ear, Old Cocoyam, Small Taro, Sweet Taro, Taro, True Taro, Yam, Dasheen

Vernacular Names

Amazonia: Pituca
Arabic: Qolqas
Bangladesh: Aro Kachu, Kachu
Brazil: Taioba, Tajoba
Cameroon: Cocoyam, Macabo
Canary Islands: Ñame
Chamorro: Suni
China: Yu, Yu Tau, Ya Nai, Wu Tau, Bun Long Wu Tau, Hung Nga Woo Tau, Yu Nai, Wu Chai
Chuukese: Eot, Oat, Óni, Oot, Sawa, Wodj, Woot, Woot, Yoot
Columbia: Papa China, Malangay, Bore, Chonque
Congo: Lengue
Cook Islands: Māmio, Taro, Wāwā (Maori)
Costa Rica: Tiquisque
Cuba: Guagui, Malanga, Malanga Isleña
Danish: Taro, Kokosyams
Dominican Republic: Tahia, Tania, Tayo, Yautía Coquito, Yautía Morada
Dutch: Taro
Egypt: Kolkas
Fiji: Dalo, Dalo Ni Vuci, Mba, Mboka, Mbotiki, Ndalo, Ndoko, Nggau, Qau, Rourou, Soli, Suli, Sulo, Votuki
French: Taro, Arouille, Arouille Carri, Colocasie, Songe, Songe Blanc, Songe Chou Chine, Songe Sauvage
German: Echte Blattwurz, Taro
Guatemala: Quiquisque
Guyana: Chinese Tayer
Haiti: Caraibe, Caraibe Manzoubelle, Malanga, Malanga Deux Palles, Malanga Thiote, Taro Bombou, Tayo Bambou, Tayo Blanc, Tayo Noir
Hawaiian: Taro, Kalo
I-Kiribati: Te Taororo, Te Taroro
India: Alti Kachu, Kachu (Bengali), Arvi, Ashukachu, Kachalu, Ghuiya (Hindu), Kesavedantu, Keshavanagadde (Kannada), Chempu, Chempakizhanna (Malayalam), Pan (Manipuri), Aaloo, Chempu, Ran Aalu (Marathi), Bal, Dawl (Mizo), Jongal Saaru (Oriya), Kachalo (Punjabi), Aaluki, Alukam, Alupam, Kachchi (Sanskrit), Sempu, Shamakkilangu (Tamil), Chamadumpa, Chamagadda, Chamakura, Shamatumpa (Telugu), Arvi (Urdu)
Indonesia: Bote, Galbu, Garbu, Gelo, Kimpil Bena, Kimpul Benal, Linyal, Lumbu Banten, Lumbu Sunda, Talas, Tales, Wulung (Javanese), Kaladi, Kombha, Talas, Tales (Madurese), Bolang, Talas, Taleus (Sundanese), Bentul, Talas, Keladi, Abalong, Dagmay, Talles, Pising, Ubigan
Italian: Colocasia, Aro Di Egitto
Jamaica: Coco
Japanese: Imo, Kiomo, Ebi Taro, Oya Imo, Saitoimo, Serebesu
Khmer: Traw, Mukhi Kachu, Pani Trao Kuk, Trao Chhouk
Korean: Thoran, Toran
Kosraean: Kohtahk, Taka
Kwara'Ae: Alo, Hui Ni Kerekere, Tiko
Laotian: Bon, Phuak
Lebanon: Kilkass
Lesser Antilles: Dachine, Edoe, Malanga
Madagascar: Sonj
Malaysia: Koadi (Jakun), Keladi, Keladi China, Birah Keladi Koadi (Malay), Rebol (Sakai)
Maldives: Ala
Marquesas: Taro, Taslo, Ta'o, Tiee
Marshallese: Jibabwãi, Katak, Kõtak, Kotāk
Micronesia: Kurau
Mokilese: Jawa
Nauruan: De Taro
Nepal: Pindalu (Corm), Gava, Karkalo (Petioles With Leaves)
New Caledonia: Dap, Di, Ekengad, Io, Inagad-Kening, Moa
Niuean: Talo
Pakistan: Arvi, Eddoes Taro
Palauan: Bisupsal, Dait, Kukau
Papua New Guinea: Ma, Me, Pa, Anega, Ba, Biloun, Guarava, Hemar, Ifem, Kukun, Mabo, Sagani

Peru: Pituca
Philippines: Linsa, Natong (Bikol), Abalong, Dagmai, Kimpoi, Lagbai (Bisaya), Amoang, Pising (Bontok), Lubigan (Ifugao), Aba, Aua (Iloko), Aba, Gabi, Latud, Pihing, Pising (Kalanguya), Robingan (Ayangann), Gabi, Lagbai (Tagalog)
Pingelapan: Sewa
Polynesia: Colulu
Pohnpeian: Enisohpoadok, Onni, Sauk, Sawa, Sawah
Portuguese: Inhame Da Africa, Inhame Do Egipto, Colcas, Dachine, Songe Inhame, Inham Branco
Pukapukan: Wāwā
Puerto Rico: Angustia, Malanga, Yautia Malanga
Russian: Taro
Samoan: Talo, Talo, Talo Niue, Tue
Satawalese: Wot Omalu
Solomon Islands: Taro, Alo, Kake, Taro Tru, Pupu, Tama
South Africa: Amadumbe, Amadumbi, Amadombie, Amadombi, Mufhongwe
Spanish: Alcocaz, Colocasia, Malanga, Nampi Tayoba, Papa China, Tayoba, Taro, Yame De Canarias
Suriname: Aroei, Chinese Tayer
Tahitian: Taro
Taiwan: Yùtou
Thai: Phuak, Bon Nam, Tun
Tokelauan: Talo
Tongan: Talo, Taro
Tongarevan: Talo, Taro
Trinidad and Tobago: Taro, Dasheen, Chinese Eddoe
Turkey: Oni
Uganda: Opela (Alur & Jonam), Mattu Midolodolo (Bugisu), Ttimba (Luganda), Oburagoi (Rukiga), Ebitekyere (Runyankore)
Ulithian: Ioth
Vanuatu: Pes, Peta Vembierr
Venezuela: Chino, Danchi, Ocumo Chino, Ocumo Culin, Papa China
Vietnam: Khoai Môn, Khoai Nước, Khoai Nu Owc, Khoai Au Nu'oc Bang, Khou-Au Ku'oc Tuiang Mon Nu Owc, Khoai So
Wallisian: Talo
West Africa: Old Cocoyam, Bari, Koko, Ya Beré
Woleaisan: Uot, Woot
Yapese: Lak, Mal, Mul, Uot, Wot, Wot Omalu

Origin/Distribution

C. esculenta is native to tropical Asia (Govaerts 2014). Taro appears to have originated in India and spread eastwards to Burma and China and southwards to Indonesia. Subsequently, it was taken to Japan, Melanesia, Polynesia and Hawaii; in historical times, it spread to Egypt and the eastern Mediterranean, thence to Africa, to the Guinea coast and to the Caribbean. It has been actively cultivated throughout tropical and subtropical regions. Today, it is grown throughout the West Indies and in West and North Africa. In Asia, it is widely planted in south and central China and is grown to a lesser extent in India. It is now a staple food in many islands of the Pacific including Papua New Guinea.

Isozyme studies of 1,427 cultivars and wild taro forms from Oceania and Asia conducted by Lebot and Aradhya (1991) indicated that the majority of Indonesian cultivars were different from the Philippines. Taro cultivars in Oceania were suggested to have a narrow genetic base introduced from Indonesia which was found to have the greatest taro diversity. AFLP analysis confirmed the isozyme results, and two distinct gene pools were found, one in Southeast Asia and the other in the Pacific (Lebot et al. 2004).

Agroecology

C. esculenta can be found growing naturalised or native mainly in moist forests and wet areas in riparian habitats, riverbanks, along streams, marshes and canals or cultivated near farmhouses, in water fields or as under-planting in coconut groves (Ibrahim et al. 1983; Safo-Kantaka 2004; Acevedo-Rodríguez and Strong 2005; Langeland et al. 2008). It can also be found in secondary forests, roadsides and disturbed areas near to abandoned crop fields (Wagner et al. 1999; Acevedo-Rodríguez and Strong 2005). Taro thrives in hot, humid conditions, with

daily average temperatures of 21–27 °C with an annual rainfall of 250 mm to 1,750 mm evenly distributed during the growing period. It grows from sea level to 2,400 m elevation. It is primarily adapted to a moist environment. It can be grown under submerged or flooded conditions or on artificial elevations in swamps, as well as by dry cultivation in areas with high rainfall. It tolerates a wide range of soil types but does best on deep, well-drained, friable loams, particularly alluvial loams, with a high water table and a pH range of 5.5–6.5. It does best in partial shade but tolerates full sun with adequate water supply.

Edible Plant Parts and Uses

In China, caudices, corms and cormels are boiled, or cooked, with meat or seafood (Hu 2005). Sapal is a traditional fermented food in Papua New Guinea made by mixing cooked, grated taro corm with coconut cream and allowing it to ferment at ambient temperature (Gubag et al. 1996). The fermentation was primarily due to heterofermentative lactic acid bacteria predominantly *Leuconostoc mesenteroides* or *Leuconostoc paramesenteroides*. Achu is a thick porridge obtained by cooking and pounding taro corms and cormels in a mortar (Njintang and Mbofung 2006). Taro corm is a staple food in tropical Africa; in Cameroon, it is widely known for its famous dish achu (Ejoh et al. 1996). The corms are eaten boiled, fried or roasted as a side dish or are used for making fufu in Africa. The corm is also sliced and fried into taro chips. In Indonesia, the corm is sliced and pieces fried in coconut oil or roasted and eaten mixed with aren palm sugar syrup or without (Ochse and Bakhuizen van den Brink 1980). Thin corm slices are also deep-fried to make kripik. The boiled or steamed corms are also eaten sprinkled with grated coconut. The steamed or roasted corm is pounded and boiled with rice with added salt.

In Hawaii and parts of Polynesia, the corms are cooked and pounded into a paste that is allowed to ferment to produce 'poi'. A steamed pudding is made from grated taro and coconut. In addition to poi, taro is used in baby food, chips, taro bread (Moy and Nip 1983 and taro sorbet (Hong and Nip 1990). Results indicated that precooked taro flour can replace as locust bean gum (LBG), carboxymethylcellulose (CMC) and carrageenan gum (CG) successfully in tropical fruit (guava, pineapple and passion fruit) sorbet manufacturing without noticeable change in functional properties. In Hawaii, some of the taro food products available include poi, a product of steamed kalo which has been peeled and pounded into a thick paste (*pa'i 'ai*) and mixed with water until the desired consistency is achieved; poi in the bag, poi in the jar (baby food), dehydrated poi, deep-fried taro chips (snack) and taro baskets or nests (a restaurant dish), taro bread or rolls, taro pancakes, tropical fruit–taro flakes, taro cookies, ice cream sorbets, extruded products, baked goods or pancakes, patties made from kalo and soy products instead of beef (taro burgers) and *Kūlolo* (a sweet pudding made from baked or steamed grated kalo and coconut cream) (Greenwell 1947; Nip 1979a, b; Nip 1980; Moy et al. 1980; Moy and Nip 1983; Hong and Nip 1990; Nip et al. 1994; Abbott 1992; Hollyer et al. 2000). In other countries, other forms of taro such as taro flakes (Taiwan), frozen taro chunks (China), dried taro chips (Fiji and Western Samoa) and frozen taro cake (Taiwan) are also available (Nip 1980). Taro is also made into baby food-type products, taro flour, taro meal or grits, canned taro, extruded products (rice, noodles and macaroni), fermented alcoholic beverage and gum replacer. Noodles can be prepared using 50 % taro flour and remaining equal proportions of rice and pigeon pea flours (Kaushal and Sharma 2013). The rehydration weight of noodles decreased with the increase in drying temperature.

Small-scale production of drum-dried tropical fruit (guava, papaya, mango, pineapple) – taro flakes – were reported by Nip (1979a, b). Taste of the tropical fruit–taro flakes was acceptable upon storage at 38 °C for 24 weeks. Studies by Moy et al. (1980) showed that taro flour could be extruded successfully into rice, noodle or macaroni by proper adjustment of initial dough temperature and moisture content. Protein enrichment (incorporation of mung bean flour or soy protein) improved to a limited extent the overall quality of extruded taro samples. Snap-type cookie formulations

with taro flour as one of the major ingredients was developed by first modifying the taro flour and wheat flour ratios, followed by modification of the taro flour, wheat flour, sugar and shortening ratios (Nip et al. 1994). A drop-type chocolate chip cookie formulation was developed by replacing 51 % of the wheat flour with taro flour in a commercial formulation. Both cookie formulations developed were found to be highly acceptable. Three kinds of taro paste were prepared with taro–water–sugar ratios of 1:0.33:1.4, 1:0.33:0.8 and 1:0.33:0.2 (Lai et al. 1998). Results indicated that the paste with the highest sucrose concentration had the least hard texture. The declining effect of sugar on hardness development and water mobility of the low-concentration system was fructose > glucose > lactose > sucrose. Taro paste with 10 g/kg sodium stearoyl lactylate showed a larger endothermic peak for amylose–emulsifier complex but a smaller peak for retrogradation than did those with 10 g/kg MG or those without emulsifier. Studies by Emmanuel et al. (2010) suggested that acceptable bread could be produced from the addition of unblanched taro flour to wheat flour at 10 % level. This would significantly reduce the cost of production of bread and other allied products. Studies showed that flour mixtures made from taro and nixtamalised maize flour produced puffed extruded snacks with good consumer acceptance (Rodríguez-Miranda et al. 2011). Taro corm mucilages exhibit unique rheological properties with considerable potential as a food thickener and stabiliser (Njintang et al. 2014).

Taro petioles are cooked and eaten in China (Xu et al. 2001; Hu 2005) and in Myanmar (Mathew and Naing 2005); petioles and leaves are eaten in Nepal (Pandey et al. 2000) and in Vietnam where the petioles are soaked in salt water first to prevent itching in handling (Tanaka and Nguyen 2007). Zuiki, a stalk of taro, is a traditional vegetable in Japan; raw zuiki is often boiled and vinegared to eat (Terasawa et al. 2007). Leaves are also consumed in sauces and stews, purees or soups (Ferreres et al. 2012; Gonçalves et al. 2013).

Taro leaves and leaf stalks are used as a leafy vegetable and potherb for soups and sauces or as relish. They are especially popular in parts of West Africa, northeastern India, Oceania, Hawaii and the Caribbean region. In Indonesia, the petioles are cut into small pieces and cooked as sayur; the leaves are also cooked and eaten as *bobotok*, *getjok* or *loto* (Ochse and Bakhuizen van den Brink 1980). The leaves are also used to wrap salted fish which is steamed with grated coconut, lombok and salt. The lateral sprouts are also relished and are called *solor* or *seler*. In Western Cameroon, the leaves are used as a major ingredient in sauce preparations, among which black soup is the most popular, and the flowers are also used as a major ingredient in the preparation of *achu soup* (Ejoh et al. 1996). Zuiki, a stalk of taro (*Colocasia esculenta*), is a traditional vegetable in Japan. In Hawaii, the leaves are canned for local sale. Taro inflorescences are used as cooked or fried food in some parts of the Solomon Islands, Papua New Guinea and Vanuatu.

Some of the common, popular and nutritious dishes cooked with taro plant parts in the Pacific are *taro salad*, *baseisei* (Fijian style): taro stalks, lemon juice, thin coconut cream, chopped spring onion and chopped chilli; *taro with seafood*: peeled taro root, cut into cubes, shellfish or small fresh fish, coconut cream, water, chopped onion, butter, margarine or oil and taro leaves; *taro leaves in coconut cream*, *palusami* (Samoan style): coconut, taro leaves, chopped onions, banana leaves and breadfruit leaves; *taro*: chicken, taro, chopped onion, chopped green leaves (e.g. taro leaves, pumpkin leaves, sweet potato leaves), tomatoes, coconut cream, water and lemon juice; *taro in coconut cream*: taro roots, thick coconut cream, chopped onion and chopped spring onions; *taro leaf soup*: young taro leaves, wafer, butter, margarine or oil, chopped onion, milk, flour, salt and pepper; and *grated taro pudding* (Tuvalu style): taro, banana leaves, coconut cream and toddy syrup (South Pacific Commission 1992).

Botany

A glabrous, acaulescent, mainly diploid, herbaceous, perennial plant, 50–150 cm high (Plate 1), with a massive, fleshy, starchy modified subterranean stem (corm) at the base. The corms

Plate 1 Taro plant habit

Plate 2 Harvested taro corms (Fiji)

Plate 3 Harvested dalo corms (Indonesia)

Plate 4 Harvested, shaved taro corms (Vietnam)

Plate 5 Harvested taro corms (Sarawak)

vary greatly in size and are round, elongate and cylindrical, up to 35 cm long and 15 cm across (Plates 2, 3, 4, 5 and 9), often surrounded by a small number of secondary corms or cormlets called cormels (Plates 9, 10 and 11). The corm consists of the skin, cortex and core; the skin is rough and fibrous or covered with concentric rings of leaf scars and scales. The cortex and core can be white, light yellow, dark yellow, orange to pink and purple. The root system is adventitious and fibrous and white. At the apex of the corm is a whorl of petioles bearing large leaves with blades pointing obliquely downwards, 23–55 cm × 12–38 cm, cordate-hastate, sub-coriaceous, green above, glaucous below, the apex obtuse, acute or shortly acuminate, the base peltate-cordate and the margins more or less wavy (Plates 1 and 6); petioles are robust, uniformly light or dark green, with dark streaks of violet, erect, to 100 cm long, inserted 3–7 cm from base of blade and invaginate on lower 1/3 and sheathing at the petiole base (Plates 7 and 8). Inflorescences are axillary, ascending and solitary on stout peduncles nearly as long as the petiole, comprising a cylindrical, fleshy spathe, up to

Plate 6 Harvested taro leaves (Rourou)

Plate 7 Harvested taro red petioles

Plate 8 Harvested taro green petioles

Plate 9 Eddoe globose corms

Plate 10 Eddoe corm with cormels attached

Plate 11 Eddoe cormels

40 cm long; the tube is green; the blade is lanceolate, not much wider than the tube, yellow to orange, deciduous or withering; the spathe surrounds a spadix yellow, much shorter than the spathe; the sterile flower zone and the distal appendage are shorter than the fertile male and female zones.

Flowers are naked. Green pistillate flowers are located at the base of the spadix, and white sterile flowers are near its apex. Pistillate flowers have unilocular ellipsoid or obovoid ovaries, each with a single sessile, capitate stigma. Sterile flowers lack a stigma and style complex and are slightly taller than fertile pistillate flowers. Staminate flowers consist of 2–6 sessile linear anthers fused to form a synandrium. Berries are thin walled, green, ellipsoid and 3–5 mm in diameter containing a few ovoid, ridged, pale-yellow, small, albuminous seeds, 1.2–1.5 mm × 0.7–1 mm.

Nutritive/Medicinal Properties

Corm and Cormel Nutrients/ Phytochemicals

Food value of raw, taro corms (*Colocasia esculenta*) per 100 g edible portion excluding 14 % ends and skins was reported as follows (USDA-ARS 2014): water 70.64 g, energy 112 kcal (469 kJ), protein 1.50 g, total lipid (fat) 0.20 g, ash 1.20 g and carbohydrate 26.46 g; total dietary fibre 4.1 g and total sugars 0.40 g; minerals, calcium 43 mg, iron 0.55 mg, magnesium 33 mg, phosphorus 84 mg, potassium 591 mg, sodium 11 mg, zinc 0.23 mg, copper 0.172 mg, manganese 0.383 mg and Se 0.7 µg; vitamins, vitamin C (total ascorbic acid) 4.5 mg, thiamine 0.095 mg, riboflavin 0.025 mg, niacin 0.600 mg, pantothenic acid 0.303 mg, vitamin B6 0.283 mg, folate (total) 22 µg, choline (total) 17.3 mg, vitamin A 76 IU, β-carotene 35 µg, β-cryptoxanthin 20 µg, vitamin E (α-tocopherol) 2.38 mg and vitamin K (phylloquinone) 1.0 µg; phytosterols 19 mg; lipids, fatty acids (total saturated) 0.041 g, 16:0 (palmitic acid) 0.035 g and 18:0 (stearic acid) 0.006 g; fatty acids (total monounsaturated) 0.016 g, 18:1 undifferentiated (oleic acid) 0.016 g; fatty acids (total polyunsaturated) 0.083 g, 18:2 undifferentiated (linoleic acid) 0.058 g and 18:3 undifferentiated (linolenic acid) 0.025 g; and amino acids, tryptophan 0.023 g, threonine 0.069 g, isoleucine 0.054 g, leucine 0.111 g, lysine 0.067 g, methionine 0.020 g, cystine 0.032 g, phenylalanine 0.082 g, tyrosine 0.055 g, valine 0.082 g, arginine 0.103 g, histidine 0.034 g, alanine 0.073 g, aspartic acid 0.192 g, glutamic acid 0.174 g, proline 0.060 g and serine 0.092 g. Taro corm was found to contain the following phytosterols (mg/100 g): total sterol 23.55 mg, cholesterol 0.64 mg, campesterol 2.02 mg, stigmasterol 6.62 mg and β-sitosterol 14.27 mg (Osagie 1977).

Nutrient and oxalate composition of air-dried corms of six American Samoa taro varieties: crude protein 2.9–5.0 %, crude fat 0.31–0.64 %, ash 1.97–3.29 %, carbohydrate 92.3–94.47 %, gross energy 3.32–4.40 kcal/g, thiamine 14–188 mg/100 g, minerals (µg/g) N 5,300–7,100 µg, P 1,200–2,520 µg, K 10,100–17,600 µg, Ca 580–840 µg, Mg 920–1270 µg, Na 84–397 µg, Mn 2.6–5.8 µg, Fe 48–78 µg, Cu 5.3–9.3 µg, Zn 24–41 µg, B 7.9–9.6 µg, Mo 0.3–0.6 µg and total oxalate 1.76–3.52 mg/g (Nip et al. 1989). The nonnutritive fibre components were total fibre 6.04–7.38 %, acid detergent fibre 2.54–3.72 %, neutral detergent fibre 3.75–5.64 %, cellulose 1.62–2.27 %, lignin 0.85–1.48 % and pectin 1.58–2.73 %.

Proximate nutrient composition (fresh weight basis) of taro corms reported by Onwueme (1994) was moisture 63–85 %, carbohydrates (mainly starch) 13–29 %, protein 1.4–3 %, fat 0.16–0.36 %, crude fibre 0.6–1.18 %, ash 0.6–1.3 %, vitamin C 7–9 mg/100 g, thiamine 0.18 mg/100 g, riboflavin 0.04 mg and niacin 0.9 mg/100 g. Proximate nutrient per 100 g edible portion of taro corms reported by Lambert (1982) was moisture 77.5 %, energy 85 cal, carbohydrates 19 g, protein 2.5 g, fat 0.2 g, fibre 0.4 g, Ca 32 mg, P 64 mg, Na 7 mg, K 524 mg, Fe 0.8 mg, vitamin A trace IU, vitamin C 10 mg, thiamine 0.18 mg, riboflavin 0.04 mg and niacin 0.9 mg. Proximate nutrient composition of taro corms grown along the Lake Victoria Basin in Tanzania and Uganda (pooled values g/100 g DM) was moisture content C 68.7 %, ash 2.69 g, crude protein 3.8 g, crude fibre 1.34 g, fat 0.44 g, carbohydrates 23.03 and minerals (mg/100 g DM) K 715.39 mg, P 134.30 mg, Cu 0.19 mg, Fe 3.48 mg, Zn 4.32 mg, Mn 3.68 mg, Ca 68.67 mg, Mg 83.67 mg and Na 13.18 mg (Ndabikunze et al. 2011).

Taro corms (three taro accessions) contained the following carotenoids: lutein 2.3–3.4 %, 13-*cis*-β-carotenene 0.1–0.7 %, all-*trans*-β-carotene 0.502.7 % and 9-*cis*-β-carotene 0.2–0.5 % (Champagne et al. 2010). Minimum and maximum values for the carotenoids in taro corm in terms of μg/100 g fresh weight were determined as xanthophylls lutein tr (trace)–11.4 μg, zeaxanthin n.d. (not determined) to tr; 13-*cis*-β-carotenene tr–46.7 μg; all-*trans*-β-carotene tr–146.1 μg; 9-*cis*-β-carotene tr–18 μg; acyclic carotenes phytoene n.d. to tr; neorosporene n.d.; and vitamin A tr–17 μg RAE/100g FW. The concentrations of 15 elements (Al, Ca, Cl, Mg, Mn, Br, Co, Cr, Cs, Fe, K, Na, Rb, Sc, Zn) and NO_3^-, SO_4^{2-}, $H_2PO_4^-$, Cl^-, malate and oxalate were analysed in taro from Japan and China (Kobayashi et al. 2011). The mean concentrations of $H_2PO_4^-$, Co, Cr and Na significantly differed between taro grown in Japan and that grown in China.

Taro quality estimated by near-infrared reflectance spectroscopy (NIRS) showed high variance in cross-validation (r^2_{cv}) for starch (0.89), sugars (0.90), proteins (0.89) and minerals (0.90) but poor response for amylose (0.44) and cellulose (0.61) (Lebot et al. 2011). It was found that NIRS could be used to predict starch, sugar, protein and mineral contents in taro corms with reasonably high confidence.

Colocasia esculenta corms were found to contain Na (1521.34), K (4276.04), Mg (415.07), Ca (132.43), Fe (8.66), P (72.21), Zn (2.63), Mn (0.13) and Cu (0.78) (mg/100 g) (Njoku and Ohia 2007). The mean values of the proximate composition of *Xanthosoma sagittifolium* (white flesh), *X. sagittifolium* (red flesh) and *Colocasia esculenta* cormels evaluated were crude protein 2.98–5.50 g/100 g, total fat 0.28–0.97 g/100 g, ash 1.56–2.98 g/100 g, starch 12.2–36.0 g/100 g and crude fibre 1.11–3.00 g/100 g (Sefa-Dedeh and Kofi-Agyir 2004). Potassium was the most abundant mineral (763–1451 μg/100 g) with appreciable amounts noted for zinc (17–51.1 μg/100 g), magnesium (46.7–85.0 μg/100 g) and phosphorus (41.6–63.1 μg/100 g). Oxalate compositions of the fresh samples were in the range of 254–381 μg/100 g for the *X. sagittifolium* (red flesh), 302–323 μg/100 g for the *X. sagittifolium* (white flesh) and 328–460 μg/100 g for the *Colocasia esculenta*. No significant differences were found between the oven-dried and solar-dried samples (Njoku and Ohia 2007). However, drum drying reduced the oxalate levels by approximately 50 % to average levels ranging from 99.9 to 191 μg/100 g.

Corm composition (based on 50 g available carbohydrate) of dasheen (*C. esculenta* var. *esculenta*) was determined as 0.4 g protein, 0.3 g fat, 52.1 g, total carbohydrate and 2.2 g fibre and for eddoes (*C. esculenta* var. *antiquorum*) 4.9 protein, 0.7 g fat, 53.3 g, total carbohydrate and 3.4 g fibre (Ramdath et al. 2004).

Nutrient composition (mean and range expressed in %DM) of taro corms of 66 parent cultivars was determined by Champagne et al. (2013) as starch 79.34, 64.60–88.20 %; sugars 4.07, 0.90–17.30 %; proteins 5.40, 2.30–9.20 %; minerals 3.93, 1.47–8.13 %; and cellulose 3.26, 1.40–7.30 %. The major and total carotenoids content (mean and range expressed in mg/g DM) found in 79 parent taro cultivars was lutein 0.16 mg, 0–1.21 mg; zeaxanthin 0mg, 0–0.14 mg; unidentified *cis* isomer of β-carotene 0.03 mg, 0–0.17 mg; 13-*cis*-β-carotene 0.37 mg, 0–2.72 mg; all-*trans*-β-carotene 0.53 mg, 0–4.77 mg; 9-*cis*-β-carotene 0.28 mg, n.d.–1.79 mg; and total carotenoids 1.47 mg, 0.09–9.77 mg.

Protein, fat, fibre, total ash and utilisable carbohydrates, respectively, in taro were found to be 6.43, 0.47, 2.63, 4.82 and 85.65 %, while the gross energy was 372.55 Kcal/100 g (Adane et al. 2013). The contents of the micronutrients, namely, Fe, Zn, Mg, Ca, Na, P and Mn were 5.86, 43.08, 7.24, 45.23, 13.81, 7.77 and 3.61 mg/100 g, respectively. Phytate for the raw product was 115.43, while oxalate and tannin were 243.06 and 47.69 mg/100 g, respectively. The protein content was lower by 9.37 % and 8.46 %, respectively, in the boiled and fermented products. The crude fat content was significantly different from the crude fat content of the boiled product which was 0.87 %. Fermentation resulted in a lower level of fibre which was 6.44 % and phytates of about 84.75 %. Boiling of taro resulted in a higher value of oxalate (70.9 %).

The fat, sugar, starch and crude protein content in fresh taro cormels varied from 0.08 to 0.98, 0.2 to 1.5, 7.5 to 24.8 and 1.0 to 2.8 %, respectively (Sen et al. 2005). Cormels provide 166–519 kJ of energy/100 g fresh weight. Moreover, cormels were a good source of minerals including potassium, calcium, phosphorus and iron; a moderate source of zinc and copper; and an inadequate source of manganese. The contents of the trypsin inhibitor, total oxalate, soluble oxalate and calcium oxalate varied from 52 to 1,020 Trypsin Inhibitory Unit (TIU)/g, 8–130, 4–89 and 4–93 mg/100 g, respectively.

Proximate nutrient composition of raw taro was determined as moisture 6.54 %, crude ash 2.44 %, crude fibre 3.01 %, crude protein 7.79 %, crude fat 0.65 %, carbohydrate 86.11 % and minerals (mg/100 g) Ca 55 mg, Fe 2.95 mg and Zn 1.67 mg (Alcantara et al. 2013). Proximate nutrient composition of taro powder was determined as moisture 6.21 %, crude ash 2.78 %, crude fibre 3.10 %, crude protein 8.07 %, crude fat 0.45 %, carbohydrate 85.60 % and minerals (mg/100 g) Ca 64.84 mg, Fe 4.06 mg and Zn 1.84 mg. Proximate nutrient composition of taro noodles was determined as moisture 3.10 %, crude ash 1.39 %, crude fibre 1.24 %, crude protein 3.23 %, crude fat 0.19 %, carbohydrate 59.92 % and minerals (mg/100 g) Ca 32.41 mg, Fe 2.84 mg and Zn 1.29 mg. Proximate nutrient composition of taro cookies was determined as moisture 1.07 %, crude ash 0.24 %, crude fibre 0.27 %, crude protein 0.69 %, crude fat 0.13 %, carbohydrate 36.69 % and minerals (mg/100 g) Ca 13.90 mg, Fe 3.47 mg and Zn 0.87 mg.

Mean values obtained for *Colocasia esculenta* var. *antiquorum* and *Xanthosoma sagittifolium* in g/k dry weight were crude protein 37.5–73.6, total fat 0.9–8.7, ash 28.7–77.7, crude fibre 4.3–42.0, total sugars 5.9–42.5 and starch 509.1–705.7 (Agbor-Egbe and Rickard 1990). The main sugars identified were fructose, glucose, sucrose and maltose. The amino acids with the highest concentrations were aspartic acid, glutamic acid and arginine. A significant reduction in starch content (to 39.8–47.4 g/kg) and increase in total sugar content (to 8.0–11.6 g/kg) occurred during the storage of cormels for 2 weeks under tropical ambient conditions (24–29 °C; 86–98 % RH). No significant differences between fresh and stored cormels were found in crude protein and amino acid contents.

Studies showed that taro contained 63.6–72.4 % moisture and upland-cultivated taro corms retained a higher moisture content compared to paddy taro (Huang et al. 2007). Taro corms also contained 21.1–26.2 % starch and 1.75–2.57 % crude protein and provided total energy in the range of 97.1–118.3 kcal/100 g fresh taro. Taro corms had reasonably high contents of potassium and magnesium, whose ranges were 2,251–4,143 and 118–219 mg/100 g dry matter, respectively. Upland-cultivated taro tended to have higher mineral content than paddy taro. Taro corms are moderately good sources of water-soluble vitamins, such as thiamine, riboflavin and ascorbic acid, compared to other tropical roots. A higher soluble sugar content in upland-cultivated taro corms was found than in paddy taro. The cultivar Mein contained higher soluble fibre levels than two other cultivars. Total oxalate and phytic acid levels of taro corms were in the range of 234–411 and 139–169 mg/100 g dry matter, respectively, which included 60–75 % of water-soluble oxalate. Essential amino acid contents of taro proteins from both paddy and upland cultivation were fairly similar to the FAO reference pattern, except for the contents of sulfur-containing amino acids, tryptophan and histidine.

When compared with uncooked taro corms, the ash and crude fibre contents of taro accessions significantly decreased after cooking (Lewu et al. 2009). The moisture content, crude protein, crude lipid, carbohydrate and caloric contents increased with cooking in all the accessions, except UFCe1 and UFCe5 where the crude lipid content was reduced. The results indicated that cooking enhanced the carbohydrate, energy and protein contents of the tubers. They further showed that the tubers could be used for allergic infants, old people and invalids since the fibre contents were still appreciably high despite the slight reduction after cooking the tubers. The change in taro corm boiling time led to a significant reduction in the moisture, reducing sugars,

total sugars, crude fat, crude fibre, total phenolic compound contents and iodine affinity of starch, whereas the total carbohydrate content, water absorption capacity, water solubility index, paste clarity and foam capacity increased significantly (Amon et al. 2014).

Studies showed that irrespective of the cooking medium (water, tamarind solution, lemon solution or steam), the hardness, soluble proteins and resistant starch significantly decreased during cooking, while absorbance at 280 and 450 nm, iodine index, degree of cell separation and soluble sugars significantly increased (Aboubakar et al. 2009). A significant correlation was observed between the hardness and the iodine value, resistant starch, soluble sugars and degree of cell separation, suggesting multiple mechanisms involved in the softening of taro corms during cooking. It was observed that steam cooking of the slices induced the highest softening, while boiling in water induced the lowest softening of the corms. However, cooking in tamarind and lemon solutions induced a bitter and acid taste to the corms. While no consistent change was observed during steaming, significant reduction was observed in the oxalate content during boiling probably due to leaching in boiling solutions and acid hydrolysis.

Taro Starch

Taro corm starch contained 28 % amylose (Amin 1955). Periodate oxidation, methylation and hydrolysis revealed a chain length of 490 glucose units for amylose and 22 units for amylopectin. The results were similar to potato starch. The mean particle sizes of the taro (Ishikawa-wase and Takenokoimo) starches were 1.4 μm and 2.0 μm, respectively (Sugimoto et al.1986). The susceptibilities of the taro (Ishikawa-wase and Takenokoimo) starch granules to hog pancreatin were similar to that of normal maize starch granules. Hollows were observed on the surface of taro (Ishikawa-wase and Takenokoimo) starch, after an attack by pancreatin. The initiation temperatures for gelatinisation were 62 °C for Ishikawa-wase and 73 °C for Takenokoimo. The onset temperatures were 65 °C for Ishikawa-wase and 76 °C for Takenokoimo. The amylose contents of isoamylase-debranched starches were 13.5 % for Ishikawa-wase and 10.8 % for Takenokoimo. On X-ray diffractometry, the taro (Ishikawa-wase and Takenokoimo) starches showed A-type patterns. Taro starch was found more susceptible to pancreatin hydrolysis than other tuber and root starches (Sugimoto et al. 1979). Starch granules in the slices of taro seed corms, mother corms, cormels, secondary cormels and third cormels were found to be polygonal in shape and showed similar sizes and shapes during development (Sugimoto et al. 1987). The initiation temperature for gelatinisation of starch granules, as judged on photopastegraphy, tended to be lower in the later stages of development than in the earlier stages. The amylose content of starch granules changed in the following increasing order: mother corm < cormel. On X-ray diffractometry, starch granules prepared from corms and cormels grown under a high environmental temperature showed A-type patterns; however, those prepared from corms and cormels grown under a lower environmental temperature showed Ca-type ones.

Starch granule size was found to vary considerably among the ten different taro accessions, C-9 starch having the largest average granule size (5.19 μm) while the lowest was recorded for C-46 (2.96 μm) (Moorthy et al. 1992). The total amylose content varied between 14 and 19 % with C-9 starch having the highest value. Soluble amylose content ranged from 4 to 11 %. C-9 starch had the highest peak viscosity, almost twice as much as the others. The swelling volumes ranged from 25.0 to 60.0 mL/g with C-266 starch having the highest swelling volume.

Starch contents of the flours prepared from taro corms of Bun-long, dasheen, Hawaii Red (Lehua), Hawaii White and Niu'e varieties varied from 73 to 76 % (Jane et al. 1992). Starch yields of the flours varied from 51 to 58 %. Nitrogen contents varied from 0.33 to 1.35 % and from 0.014 to 0.025 % in the flours and starches, respectively. Taro starches had irregular, polygonal shapes and small granular sizes. Among the five varieties, Bun-long had the smallest average

diameter (2.6 μm) and largest (3.76 μm) in dasheen starch. Amylose contents varied from 18 to 22 %. Molecular sizes of the taro amyloses ranged from degree of polymerisation (DP) 150–550. Branch chain lengths of the taro amylopectin varied from DP 16.8 to 18.4 and from DP 37.2 to 40.5 for short and long branches, respectively. All five starch varieties gave an A-type X-ray diffraction pattern. The taro starches contained 0.23–0.52 % lipid and 0.017–0.025 % phosphorus. The onset gelatinisation temperatures of the taro flours varied from 72 to 79 °C, whereas those of the taro starches ranged from 69 to 74 °C. Retrogradations of the starches and the flours, as measured by their enthalpy changes, appeared to be more severe than that of corn starch. Taro starch pastes had significantly higher viscosities than their flour counterparts.

Significantly smaller sizes (0.05–0.08 μm) of starch granules were observed for *Colocasia esculenta* than for the *X. sagittifolium* (red-flesh and white-flesh) varieties (Sefa-Dedeh and Kofi-Agyir 2002). Significant differences in raphide sizes were observed among the varieties, with the *C. esculenta* having more pronounced needlelike structures. *C. esculenta* showed lower hot paste viscosity but higher thermal stability than the *Xanthosoma* species. Peak viscosity was highest in the *X. sagittifolium* (red-flesh) variety, while the white-flesh variety showed the least tendency to retrogradation. *Xanthosoma sagittifolium* and *Colocasia esculenta* starches were white in colour and had granule sizes varying significantly in length (6.47–13.63 μm) and width (5.36–8.45 μm), while amylose content ranged from 11.55 to 33.77 % (Falade and Okafor 2013). Peak, breakdown and final viscosities, pasting temperature (84.53–88.75 °C) and time (4.55–4.97 minutes) varied significantly among cultivars. Also, water absorption capacity (21–36 %), pH (4.8–5.3), gelling point (60.5–69.5 °C), foam capacity (4.46–18.28 %), bulk density (0.14–1.15 g/mL) and swelling power (2.31–10.09) varied significantly among the cultivars. Average yield of the starches varied significantly from 10.03 to 18.61 %.

Starch yields prepared from the flours of six taro varieties varied between 66.5 % for cv. KW2 and 86.6 % for cv. RIE (Aboubakar et al. 2008). The protein content varied from 2.9 % for cv. KW1 to 4.9 % for cv. CN in the flours. Taro starch had irregular, polygonal shapes and small granular sizes. The amylose contents varied from 14.7 to 30.85 %. The taro starch contained 0.2–0.6 % lipids and 2 % ash. The onset gelatinisation temperatures of the taro flours varied from 55.2 to 65.49 °C, whereas those of the starches are between 48.08 for KW2 and 64.37 °C for KW1. Retrogradation of the starches and the flours appeared to vary significantly between the varieties. The water absorption capacity varied from 240 to 470 % and from 60 to 250 % for the flours and starches samples, respectively. Taro flours had higher solubility index than their starch counterparts. Among the varieties, RIN and CE starches had the highest solubility, whereas KW1 starch had the lowest.

Studies showed that the amylose content of the starch isolated from *Xanthosoma sagittifolium* was higher than those shown by *Colocasia esculenta* and *Manihot esculenta* starches (Pérez et al. 2005). The phosphorous content was higher in *Xanthosoma sagittifolium* than in *Colocasia esculenta* or the commercial *Manihot esculenta* starches. The gelatinisation profile range was wider in *Manihot esculenta C*. than taro and tannia. *C. esculenta* flour showed higher crude fat, total, soluble, insoluble dietary fibre and mineral (P, Ca, Fe, and Zn) contents, whereas *X. sagittifolium* flour showed higher starch, ash and reducing sugar content (Pérez et al. 2007). *X. sagittifolium* flour showed higher titratable acidity and relative density values, being darker and more yellowish than its counterpart. *X. sagittifolium* flour showed higher gelatinisation temperature than *C. esculenta* flour. Parameters such as viscosity during the holding time (95 °C for 30 minutes), viscosity at 50 °C, setback, and consistency were lower in *C. esculenta* flour than in *X. sagittifolium* flour. The viscosity peak and breakdown indices were higher in *C. esculenta* flour than in the *X. sagittifolium*. Taro starches gave higher potassium and phosphorus but lower calcium levels than the cassava and corn starches (Mweta et al. 2010). The shape of the starch granules varied from spherical to polygonal with taro

starches displaying smaller-sized granules than cassava and corn starches. Taro starches exhibited amylopectin molecules of higher molecular weights but amylose molecules of lower molecular weights than cassava and corn starches. Taro starches exhibited lower water absorption capacity and swelling power, paste clarity and viscosity but higher solubility, gelatinisation temperatures and retrogradation tendencies than cassava and corn starches.

At 95 °C, heat-moisture-treated, oxidised and acetylated taro starches were more soluble, while cross-linked starch was less soluble as compared to raw starch (Alam and Hasnain 2009). Heat-moisture-treated and chemically modified starches had lower swelling power (at 95 °C) than that of isolated starch. Swelling power and solubility were found to be a function of pH, and it was observed that all these modified starches had greater swelling capacity and solubility at pH 2.0 and 10.0. of taro starch (in dry basis) was 81 %, and this starch had low amylose content (2.5 %) (Agama-Acevedo et al. 2011). Taro starch granules showed a mixture of shapes with sizes between 1 and 5 μm and presented an A-type XRD pattern with a crystallinity level of 38.26 %. Solubility and water retention capacity did not change in the temperature range of 50–70 °C, and thereafter, they increased as temperature increased too. Taro starch showed high peak viscosity due to its high amylopectin content. The peak temperature of gelatinisation of taro starch was 80.6 °C with an enthalpy value of 10.6 J/g, with low retrogradation rate due to its low amylose content. Weight-average molar mass (Mw) and gyration radius (Rz) of taro starch were 1.21×10^9 g/mol and 424 nm, respectively. Taro tuber could be an alternative for starch isolation with functional and physicochemical characteristics for food and nonfood applications.

Results of studies found that taro starches from corms planted in summer had the largest granule size, a low uniformity of gelatinisation and a high tendency to swell and collapse when heated in water and showed an elasticity during gelatinisation that was higher than that of starches planted in the other seasons (Lu et al. 2008). In addition to the planting season and the variety, rheological and pasting properties of taro starches studied were influenced not only by the amylose content but also by the chain-length distribution of amylopectin, whereas swelling power and solubility only depended on the amylose content of starch. Taro starch with relatively high amylose content, high short-to-long-chain ratio and long average chain length of long-chain fraction of amylopectin displayed high elasticity and strong gel during heating. Starch was isolated from taro corms with 98 % purity and 10.4 % amylose content (Simsek and El 2012). By application of heating, autoclaving, enzymatic debranching, retrogradation and drying processes to taro starch for two times, resistant starch (RS) content was increased 16-fold (35.1 %, dry basis).

The addition of mucilage caused a remarkable increase in the temperature of gelatinisation for taro, yam and sweet potato starches due to the competition for water during starch gelatinisation (Huang et al. 2010). Furthermore, adding mucilage increased the phase transition temperature range (Tc–To) of starches but decreased the enthalpy (ΔH). Addition of mucilage did not change the pasting temperature for taro starch. The peak viscosity of taro and sweet potato starches decreased significantly as their mucilages were added into each starch suspension system.

Starch was extracted from taro corms with a yield of 858 g/kg, and it had 269.2 and 554.8 g/kg of amylose and amylopectin contents, respectively (Antonio-Estrada et al. 2009). Maltodextrins with dextrose equivalent (DE) of 15.12 and 17.48 % were obtained from taro starch by enzymatic hydrolysis at 95 °C during 48.6 and 79.4 minutes, respectively. Moisture content of taro maltodextrins (TM) was similar to commercial corn (CCM) maltodextrins for each DE (15 or 17.5 %), whereas the ash content of TM was higher than CCM with DE of 15 %. Fat content was higher in TM than CCM with DE of 15 or 17.5 %. There was no difference in pH between TM and CCM with the same DE. Average degree of polymerisation (DP) was lower in TM than CCM with DE of 15 %. Average molecular weight of TM was lower than CMM.

Taro Flour

Taro flours studied had lower protein, fat and starch contents and higher sugar and fibre contents than wheat flour (Godoy et al. 1992). Water and fat absorption capacities of raw and blanched taro flours were higher, whereas the foam capacity, foam stability, whippability and nitrogen solubility were generally inferior compared to wheat flour. Addition of salt up to 2 % concentration in the flour suspension increased the foam capacities of all flours studied. The least concentration endpoint (LCE) for gelation of both raw and blanched taro flours was comparable to that of wheat flour. While inferior to wheat flour in composition and most functional tests, the utilisation of taro flour may be enhanced by incorporation of protein supplements. Proximate analyses of the taro flours indicated they were low in fat, protein and ash but rich in starch and total dietary fibre (Tagodoe and Nip 1994). Heat processing affected the functional properties of taro flour.

Chemical composition (dry weight basis) of six taro varieties grown in Cameroon and Chad was reported as moisture 61.10–81.55 %, ash 3.54–5.65 %, total fat 0.34–0.73 %, crude starch 41.27–64.44 %, amylase 17.07–35.73 %, crude proteins 2.57–5.41 %, available carbohydrates 33.29–77.83 % and crude fibre 0.35–3.78 % (Mbofung et al. 2006). They reported the following amino acid composition (in g/100 g dry weight) of taro flours, respectively, from Ibo Ngdere and Sosso Chad varieties: essential amino acids, threonine 4.45, 4.10 g; isoleucine 4.04, 4.19 g; leucine 10.72, 10.37 g; lysine 5.43, 5.55 g; methionine + cysteine 0.12, 0.10 g; phenylalanine 5.93, 5.57 g; tyrosine 1.46, 1.05 g; valine 6.40, 6.27 g; and histidine 2.22, 2.52 g; nonessential amino acids, alanine 5.93, 6.08 g; aspartic acid 16.07, 15.23 g; glutamic acid 12.03, 12.33 g; glycine 6.18, 6.08 g; proline 4.78, 4.73 g; serine 6.07, 5.76 g; and arginine 6.32, 6.72 g; and other amino compounds, ethanolamine 0, 0.35 g; ornithine 0.11, 0.17 g; serine 0, 0.26 g; and GABA 1.61, 2.40 g. The major sugar found was a disaccharide. Wide variations were observed in the functional properties of the flours, water absorption capacity 242.45–374.86 %, oil absorption capacity 174.37–186.53 g/100 g, water solubility index 18.55–27.64 g/100 g, foam capacity 9.75–13.5 mL/100 mL, emulsion activity 38.41–43.45 mL/100 mL, emulsion stability 25.87–42.52 mL/100 mL, blue value index 5.69–28.37 eq. DO/100 g flour, bulk density 0.57–0.71 g/mL, titratable acidity 0.68–0.99 g oxalic acid/100 g and pH 6.24–7.04. Njintang et al. (2014) reported the proximate composition (g/100 g) of flour from six taro varieties as moisture 8.2–9.6 g, proteins 2.9–4.9 g, carbohydrates 90.5–94.8 g, lipids 0.3–1.17 g and ash 1.3–5.5 g.

C. esculenta flour showed higher crude fat; total, soluble and insoluble dietary fibre; and mineral (P, Ca, Fe, and Zn) contents, whereas *X. sagittifolium* flour showed higher starch, ash and reducing sugar content (Pérez et al. 2007). *X. sagittifolium* flour showed higher titratable acidity and relative density values, being darker and more yellowish than its counterpart. *X. sagittifolium* flour showed higher gelatinisation temperature than *C. esculenta* flour. Parameters such as viscosity during the holding time (95 °C for 30 minutes), viscosity at 50 °C, setback and consistency were lower in *C. esculenta* flour than *X. sagittifolium* flour. The viscosity peak and breakdown indexes were higher in *C. esculenta* flour than in the *X. sagittifolium*. Taro flour was significantly different from other flours in exhibiting the highest carbohydrate and water absorption and lower protein, foaming capacity and setback viscosity (Kaur et al. 2013). Peak viscosity of taro flour was lower in comparison to potato flour but higher than that of soya and corn flours. Change in boiling time lead to a significant reduction in moisture, sugars, crude fat, crude fibre, total phenolic content and iodine affinity of starch, whereas total carbohydrate, water absorption capacity, water solubility index, paste clarity and foam capacity increased significantly (Amon et al. 2014). The crude protein and total ash contents of the flours from taro corm were not affected significantly by the change in boiling. Chemical composition and physico-functional properties of flour from raw and boiled (20 minutes) taro grown in Cote d'Ivoire was reported, respectively, as 8.1, 5.45; crude protein 2.4, 2.4 %; reducing sugar 0.73, 0.35 %; total sugar 3.3,

2.6 %; total carbohydrate 84.4, 87.4 %; crude fat 0.75, 0.6 %; crude fibre 1.7, 1.6; total ash 2.5, 2.5 %; total phenolic content 0.12, 0.076 %; minerals (mg/100 g) Ca 7.3 ,6.9 mg; Fe 8.6,4.9 mg; Mg 94.7, 93.2 mg; P 350, 354 mg; K 217.9, 221.7 mg; Na 3.7,3.9 mg; Zn 6.7,4.5 mg; and Cu 0.4, 0.43 mg; water absorption capacity 198 %, 506 %; water solubility index 7.8 %, 16 %; iodine affinity of starch 330 ppm, 220 ppm; paste clarity 28.56 %, 49.3 %T; and foam capacity 7.07, 10 %. Taro corm flours exhibited highest total carbohydrate, crude fibre, total ash contents, water absorption capacity and iodine affinity of starch and lowest crude protein and fat contents, foaming capacity and water solubility index.

Proximate composition and functional properties of taro flour was reported as moisture 7.75 %, ash 1.2 %, crude fat 1 %, protein 2 %, carbohydrate 95.7 %, bulk density 0.689 g/mL and foaming capacity 9 % (Kaur et al. 2013). Of the following flours, namely, potato, soybean, corn and taro, taro flour exhibited the highest water absorption capacity, peak viscosity and the lowest foaming capacity which afforded the flour good body for use as a thickener or gelling agent in various food products (Kaur et al. 2013). The paste formed by taro flour as a result of heating was stable upon cooling as evident by its lower setback viscosity 560 cP.

Taro flour was significantly different from other flours due to its highest ash, crude fibre, lower fat and protein content and exhibited lowest $L*$, ΔE and foaming capacity (FC) and highest WSI (water solubility index), WAC (water absorption capacity) and OAC (oil absorption capacity) as compared to rice and pigeon pea flour (Kaushal et al. 2012). Taro flour contained higher oxalate, pasting temperatures (PT), peak viscosity (PV), trough viscosity and polyphenol content while lesser amount of phytate and lower setback viscosity than rice and pigeon pea flours.

Drying at high temperatures affected the colour and the susceptibility to gelatinisation of taro flour especially that obtained from gelatinised slices (Njintang and Mbofung 2003). Precooking induced significant decrease in foam capacity and penetrometric index and increase in least gelation concentration (LGC), emulsion stability and water absorption capacity (WAC) of taro flour used in the preparation of *achu* (Njintang and Mbofung 2006). Long precooking time (>45 minutes) and drying temperature (>60 °C) induced significant reduction of the in-vitro carbohydrate digestibility of taro achu. In general, taro flour which absorbed more water tended to produce achu with high level of Newtonian compliance and retarded elastic compliance (Njintang et al. 2007). The creep steady-state shear compliance and the viscoelasticity index of achu were significantly correlated to the sensory hardness. The achu paste made from traditional and freeze-dried chips consisted of starch-filled cells encased in a continuous amylose-amylopectin gel containing some vascular elements and mucilage (Njintang et al. 2008). Their study confirmed that cooking of whole taro corms/cormels before drying constituted a good approach in the processing of taro flour, usable in the preparation of achu.

Polysaccharides/Mucilage/Proteins

Taro roots contained abundant pectin which was found to be significantly lost early during infection by the fungus *Pythium myriotylum* (Boudjeko et al. 2006). The fungus caused a significant loss of pectin probably via degradation by hydrolytic enzymes. Also, a significant decrease in galacturonic acid content occurred in infected root cell walls. Roots of taro exuded increasing concentrations of oxalate with increasing aluminium stress (Ma and Miyasaka 1998).

Cold-water-soluble polysaccharides (CWX) extracted from taro were tested for their influence on the pasting properties of taro starch and three other commercial starches (maize, rice and wheat). Addition of taro cold-water-soluble polysaccharides resulted in increased peak viscosity with maize and rice starch and a decrease in peak viscosity with wheat starch (Gaosong et al. 1997). Cold paste viscosity was decreased in wheat and taro starch, but not in maize and rice starch.

Studies had found taro to be rich in gums (mucilages). Taro mucilage yielded D-galactose (88 %), L-arabinose (8 %) and uronic acid (2 %) (Amin 1955). Hydrolysis of the main methylated

fraction gave 2,3,4,6-tetra-*O*-methyl-D-galactose (19 %), 2,3,6-tri-*O*-methyl-D-galactose (87 %) and 2,4-di-*O*-methyl-D-galactose (2.5 %). Up to 10.7 % crude taro mucilages was extracted from taro corms and tubers with boiling water (Gaind et al. 1968). Studies reported that taro mucilage could be useful as binders for pills (Gaind et al. 1968, 1969; Abdel-Akher et al. 1972; Taki et al. 1972; Yamashita and Yoshikawa 1973). Those made with mucilage of taro dissolved as fast as or faster than pills prepared with acacia gum (Gaind et al. 1969). Purified gum (mucilage) (100 g) was isolated from fresh taro corms (1 kg) (Taki et al. 1972). It consisted of galactose and arabinose in a 6:1 ratio and contained a negligible amount of protein. In another study, the mucilage composition was found to contain moisture 16 %, crude ash 4 %, crude protein 51 % and total sugar (expressed as glucose) 16 % (Yamashita and Yoshikawa 1973). On hydrolysis, eight sugars and their derivatives were identified, including glucosamine, galactose, glucose, sorbose, arabinose, ribose, rhamnose and gluconolactone. On hydrolysis, the protein was found to contain leucine, isoleucine, phenylalanine, proline, valine and/or methionine, tyrosine, alanine, glutamine, threonine, glycine, lysine, histidine, arginine, cysteine, serine and aspartic acid. The N-terminal residues appeared to be DNP-glycine, DNP-serine and DNP-aspartic acid, and in the C-terminal residue, DNP-threonine was found. In a separate study, the mucilage was found to be composed of galactose–arabinose in 8:1 ratio (Abder-Akher et al. 1972). Hydrolysis resulted in an early release of arabinose, leaving a degraded polysaccharide accounting for 91 % of the original mucilage. Approximately 70 % of arabinose residues terminated in furanose. On sulfuric acid hydrolysis, the degraded mucilage was found to have a galactose–arabinose ratio of 23:1. Periodate oxidation indicated that some galacto-pyranose molecules were nonreducing terminal residues adjacent to arabinose–furanose moieties in branches. Further investigations suggested a highly branched chain with 1,4 or 1,3 or 1,6 bonds.

Mucilage yields from the six taro varieties varied from 30.2 to 189.9 g/kg, total mucilage protein 0.3–0.5 mg/g, total mucilage carbohydrates 0.46–0.69 mg/g and uronic acid 9.4–16.3 μg/mg galacturonic acid equivalent (Njintang et al. 2014). Sugar composition (mg/g) of the mucilage comprised arabinose 4.4–8.3 mg, rhamnose 1.4–3.6 mg, fucose 1–3.5 mg, xylose 0.8–13 mg, galacturonic acid 4.2–12.3 mg, glucuronic acid 7–11.7 mg, mannose 6.4–16.2 mg, galactose 45.2–62 mg, glucose 2.7–4.1 mg, N-acetyl-galactosamine 0.12–1 mg, N-acetyl-glucosamine 0.32–0.72 mg, N-acetyl-mannosamine 0.9–4.4 mg and 2-*O*-methyl-xylose 0.21–0.9 g. Amino acid composition (mg/g) of the mucilage from varieties Ibo Ngaoundere and County Ekona was reported, respectively, as asparagine+aspartic acid 144.3, 159.7 mg; glutamine + glutamic acid 102.9, 117.3 mg; serine 77, 83.7 mg; glycine 101.7, 109.6 mg; histidine 183, 20.7 mg; arginine 60.3, 43.1 mg; threonine 62.9, 42.3 mg; alanine 81.2, 62.6 mg; proline 56.9, 50 mg; tyrosine 20.2, 26.4 mg; valine 39.9, 44.1 mg; methionine 7.8, 11.8 mg; cysteine 11.4, 13.8 mg; isoleucine 61.9, 60.4 mg; leucine 86, 86.2 mg; phenylalanine 38.4, 38.2 mg; and lysine 28.9, 30.1 mg.

Electrophoretic analysis of taro corm proteins revealed five patterns among the major cultivars (Hirai et al. 1989). These patterns were designated as E, D, I, T and A using the initials of the names of the typical cultivars Eguimo, Dodare, Ishikawa-wase, Tonoimo and Akame. Additional three protein patterns designated as M, B and C were recognised for the minor cultivars Migashiki, Binroshin and Takenokoimo, respectively. Using the biochemical and morphological analyses, seven groups were recognised, i.e. Eguimo, Dodare, Hasubaimo, Ishikawa-wase, Kurojiku, Akame and Tonoimo groups, for the non-fasciculated taro cultivars, while two, Yatsugashira and Shogaimo, groups for the fasciculated ones. The Yatsugashira group showed electrophoretic patterns common to the non-fasciculated Tonoimo group. Similarly, the Shogaimo and Dodare groups exhibited a common electrophoretic pattern. The fasciculated cultivars were, therefore, assumed to be derived from the corresponding non-fasciculated cultivars by bud mutation.

The major albumin isolated from taro corms accounted for 11 % of the total soluble protein in the corms (Carneiro et al. 1990). The native protein had an M_r of 50,000 and appeared to be composed of homogeneous subunits with molecular weight of approximately 8,300. Three isoforms were found; the major one, accounting for more than 90 % of the protein, had an isoelectric point (pI) of 6.1. The two minor ones have pI values of 5.3 and 5.7. The isolated protein had a relatively high content of essential amino acids such as phenylalanine and leucine but was poor in sulfur-containing amino acids.

The globulins from taro corms accounted for ~80 % of total soluble corm proteins (Monte-Neshich et al. 1995). The presence of two non-related globulin families, denoted G1 and G2, was detected. The G1 family comprised a large number of isoforms of 12.5 kD with isoelectric points (pIs) ranging from 5.5 to 9.5. The G2 family was composed of two sets of proteins of 24 kD (G2a) and 22 kD (G2b), with pIs near 7.5. Both protein families were highly abundant and specifically found in taro tubers. Both were partially degraded in corms during sprouting, suggesting that they may be storage proteins.

A trypsin inhibitor was isolated from taro corm and was found to belong to the Kunitz inhibitor family (Hammer et al. 1989).

A proteinaceous α-amylase inhibitor named esculentamin was purified from taro cormel of taro (Seltzer and Strumeyer 1990). This protein was shown to be an acidic (pI = 4.4) glycoprotein with a carbohydrate content of 3.64 % and a molecular weight of 11,800 Da. It contained a predominance of acidic over basic amino acids and a lack of tryptophan. Taro corm extract yielded three major densely banding group of storage proteins (Hirai et al. 1993). Approximate molecular weights of the proteins in each group were 12, 27 and 55 kD; each was composed of two or three bands. Taro differed from sweet potato, cassava and yams in that it contained two major types of storage protein: a trypsin inhibitor related to sporamin and a mannose-binding lectin (Shewry 2003).

Rekha and Padmaja (2002) also isolated an α-amylase inhibitor from taro corms. Two proteins (A-1 and B-2) with α-amylase inhibitor activity were extracted and partially purified from taro corms (McEwan et al. 2010). The molecular weight of A-1 and B-2 were estimated to be about 17,000 and 19,000 Da, respectively. The α-amylase inhibitor purified from corms of *Colocasia* collected from Himachal Pradesh was found to be a monomer glycoprotein with molecular weight of 13,900 Da (Kumari et al. 2012). An α-D-galactose with a low Km value (0.28 mM), a low molecular weight (40,000), and a neutral optimal pH (6.0) was isolated from taro stem portion (Chien and Lin-Chu 1991). Taro α-D-galactosidase also hydrolyses (1→4)- and (1→6)-linked α-D-galactopyranosyl groups from D-galactose-containing glycoconjugates. Yang and Yeh (2005) found copious amount of cysteine inhibitor in taro corms. They isolated a group-2 phytocystatin, from taro corms, named CeCPI, with molecular weight >23 kDa and demonstrated its anti-papain activity as well as antifungal activity. Tarocystatin, a group-2 phytocystatin and a defence protein against phytopathogenic nematodes and fungi and with papain inhibitory activity, was isolated from taro corm (Wang et al. 2008). It was composed of a highly conserved N-terminal region, which was homological to group-1 cystatin, and a repetitive peptide at the C-terminus. The purified recombinant proteins of tarocystatin comprised full-length (FL), N-terminus (Nt) and C-terminus (Ct) peptides with varying antifungal and papain inhibitory kinetics. FL peptide exhibited mixed-type inhibition and Nt peptide showed competitive inhibition, whereas Ct peptide possessed weak papain activation properties.

The pH-activity optimum was pH 4.6 for taro polyphenol oxidase (tPPO) (Duangmal and Apenten 1999). The temperature-activity optimum was 30 °C for tPPO. tPPO was irreversibly inactivated by 10 minute heating at 70 °C. The activation enthalpy ($\Delta H^{\#}$) and activation entropy ($\Delta S^{\#}$) for tPPO heat inactivation were 87.4 kJ/mol and −56.2 J/mol/K, respectively. The apparent substrate specificity was established from values V_{max}/K_m as 4-methylcatechol > chlorogenic acid > dl-dopa > catechol > pyrogallol > dopamine >>caffeic acid for tPPO.

A novel soluble starch synthase II (SSII) gene was isolated from taro tubers (Lin and Jeang 2005a). This 2,939 bp SSII transcript encodes 804 amino acids with a putative transit peptide of 52 residues. Expression profile showed that more transcript and protein were accumulated in tubers of 597 g fresh weight, i.e. a stage of rapid starch synthesis, than tubers of other stages. SSII was found in both soluble and granule bound portions of tuber extracts, and more SSII protein was found in aged leaves than in leaves of other stages. Another soluble starch synthase I (SSSI) cDNA was isolated from taro (Lin and Jeang 2005b). More SSSI transcript was expressed in taro leaves than in tubers, with no evident expression in petioles; and more transcript and protein were found in tubers of 597 g of fresh weight than in smaller or larger ones. Two forms of SSSI, i.e. 72 and 66 kDa, existed in leaves, and only the 66 kDa form was found in tubers. A 22.4 kDa dimeric haemagglutinin was isolated from corms of *Colocasia esculenta* cv. 'Small Taro' (Chan et al. 2010).

Bezerra et al. (1995) isolated a corm-specific gene encoding tarin (ca. 28 kDa), a major globulin of taro from a lambda Charon 35 library, using a cDNA derived from a highly abundant corm-specific mRNA as probe. Storage protein with lectin activity was identified as tarin and found to be a 12 kDa polypeptide which was purified from taro (Pereira et al. 2014). The purified protein was present in G1a/G1d isoforms. Taro-4-I, a antimetastatic polysaccharide isolated from taro corm, had a molecular weight of 200 kDa and composed of 64.4 % neutral sugars and 35.6 % uronic acid (Park et al. 2013). A lectin, *Colocasia esculenta* agglutinin (CEA), was purified from taro corms (Thakur et al. 2013). Studies showed the weight of taro cormels decreased all through during storage (Chibueze 2014). Immediately after harvest, the activity of ascorbate peroxidase was 15.49 unit/mL with a significant increase after 1 week to 73.05 U/mL. Thereafter, there was a significant decrease in activity of the enzyme after 3 weeks of storage to 33.33 U/mL. This increase in activity of ascorbate peroxidase after 3 weeks of storage may be related to increase in response to various biotic stresses.

The hydrolysate of purified cold-water-soluble taro mucilage contained galactose and arabinose was the main monosaccharide, and the main polymer present was an arabinogalactan protein (Jiang and Ramsden 1999). The yield of mucilage from 12 taro varieties varied from 75.7 to 137.0 g/kg (dry wt basis) among different varieties.

Taro corms contained mucilage and hydroxypropylmethylcellulose (Sarkar et al. 2014). The yield of mucilage fraction from taro corm varied from 30 to 190 g/kg (Njintang et al. 2014). The monosaccharide profiles revealed that galactose, mannose and arabinose were the main monosaccharides in the hydrolysate of the mucilage. From the 17 amino acids analysed, aspartic acid/asparagine (14.4–17.2 %) and glutamic acid/glutamine (10.3–13.6 %) were prominent in the mucilage as well as in the flour.

A high-purity (98 %), water-soluble gum was extracted from taro corms (Lin and Huang 1993). The major fraction of the gum had a peak molecular weight greater than 1 million daltons, with two shoulder peaks at 850,000 and 100,000 Da. D-galactose was identified to be the main constituent (61.6 %), followed by D-glucose (19.7 %) and D-arabinose (16.2 %). Small quantities of galacturonic acid and protein were also found in the gum. The gum was very soluble in water. The viscosity behaviour indicated the gum to be mainly a neutral carbohydrate polymer, probably highly branched.

Miscellaneous Phytochemicals

An antifungal compound was isolated from tubers of taro (*Colocasia antiquorum*) inoculated with black rot fungus (*Ceratocystis fimbriata*) and identified as 9,12,13-trihydroxy-(*E*)-10-octadecenoic acid together with two enzymes, lipoxygenase and lipid hydroperoxide-converting enzyme, which were responsible for the production of antifungal lipid peroxides (Masui et al. 1989). Two new dihydroxysterols were from taro corms and 14α-methyl-5α-cholesta-9, 24-diene-3b, 7α-diol and 14α-methyl-24-methylene-5α-cholesta-9, 24-diene-3α (Ali 1991). Five novel aliphatic compounds tetracos-20-en-1, 18-diol;

25-methyl triacont-10-one; octacos-10-en-1, 12-diol; pentatriacont-1, 7-dien-12-ol; and 25-methyl-tritriacont-2-en-1, 9, 11-triol were reported in the corms (Yannai 2003). Taro corm contained a high level of the antinutrient phytate 0.168 % of fresh weight (Phillippy et al. 2003).

A new sesquilignan, named colocasinol A (1), and a new acyclic phenylpropane lignanamide, named *cis*-grossamide K (2), together with ten known compounds isoamericanol A (3), americanol A (4), 2-hydroxy-3,2′-dimethoxy-4′-(2,3-epoxy-1-hydroxypropyl)-5-(3-hydroxy-1-propenyl) biphenyl (5), (-)-pinoresinol (6), (+)-yangambin (7), (-)-syringaresinol (8), kaempferol 3,7-*O*-α-L-dirhamnopyranoside (9), *trans*-cinnamic acid (10), β-sitosterol (11) and *N-trans*-feruloyl tyramine (12), were isolated from taro corm peel (Kim et al. 2010b). A new monoglyceride, (2′S)-1-*O*-(9-oxo-10(*E*), 12(*E*)-octadecadienoyl) glycerol (1), and nine fatty acid derivatives, (*R*)- (-)-(-hydroxydecanoic acid (2), (*R*)-(-)-9-hydroxydecanoic acid (3), (2*E*,4*S*)-4-hydroxy-2-nonenoic acid (4), (*S*)-15,16-didehydrocoriolic acid (5), 1-*O*-(octanoyl) glycerol (6), 12,13-epoxyoctadec-9-(*Z*)-enoic acid (7), (9*S*,10*E*,12*Z*)-10-12-octadecadienoic acid methyl ester (8), (9*S*, 10*E*,12*Z*)-10,12-octadecadienoic acid (9) and 12,13-epoxyoctadec-6(*Z*), 9(*Z*)-dienoic acid (10), were isolated from taro corm peel (Kim et al. 2010a).

The following chemicals were identified in taro corm: 8,11-octadecadienoic acid methyl ester (54.62 %), hexadecanoic acid, methyl ester (20.55 %), 9,12,15-octadecatrienoic acid, methyl ester, (*Z*,*Z*,*Z*)- (12.06 %), 9-octadecenoic acid, methyl ester, (*E*)- (6.425), 3,5-di-tert-butyl-4-trimethylsiloxytoluene (1.96 %), cyclohexanol, 2-methyl-5-(1-methylethenyl)-, (1α,2β,5α), unidentified (2.51 %) (Lee et al. 2011).

Anthocyanins isolated from taro corms and petioles were identified as pelargonidin 3-glucoside, cyanidin 3-rhamnoside and cyanidin 3-glucoside (Ghan et al. 1977). Levels of anthocyanins were highest in the skin of the corm, 16.0 mg%, with equal amounts, 4.29 mg%, in both corm and petiole. Anthocyanogens also were present. The major anthocyanins (mean, range) expressing mg/g cyanidin 3-glucoside equivalent found in 79 parent taro cultivars were total 12.33 mg, 0–306.79 mg; A21.0 0.12 mg, 0–5.58 mg; A22.1 10.06 mg, 0–243.26 mg; A24.2 0.29 mg, 0–12.74 mg; A26.6 0.72 mg, 0–32.86 mg; and A28.5 1.15 mg, 0–22.86 mg (Champagne et al. 2013). Taro corm in Vanuatu was found to be rich in flavonols (up to 326.7 mg QGE/100 g DW) like hyperoside and isorhamnetin 3-*O*-glucoside along with flavanols such as catechin and epicatechin and small amount of 3,5-dicaffeoylquininc acid (Champagne et al. 2011).

Salt tolerance in taro tissues cultured in-vitro on saline media (50–350 mOsm) was associated with increased levels of calcium oxalate, chlorophyll, protein and some secondary alkaloids (Nyman et al. 1989). The concentration of other secondary alkaloids as well as the levels of quaternary alkaloids decreased. Calcium, potassium, magnesium and sodium content of the tissues decreased with increased salinity. These findings are discussed in relation to salinity tolerance in taro.

A total of 62 aroma components were identified in cooked taro (macLeod 1990). Many of the identified components were classic volatile products deriving from a specific oxidation/degradation; others were common volatiles deriving from the action of heat on amino acids and/or sugars. The most abundant component was octane (21·10 %), and pyridine was present at the unusually high level of 18·60 %.

Sixty volatile compounds isolated by steam distillation were identified in taro corms, among which aliphatic acids (50.3 %), heterocyclic compounds (16.6 %), phenols (9.3 %) and alcohols (7.8 %) were quantitatively significant (Wong et al. 1998). The major components were palmitic acid and linoleic acid. 1-Pyrroline and 2-acetyl-1-pyrroline were identified for the first time in taro volatiles.

Antinutrients

Japanese taro cv. Akame contained the highest levels of gastric soluble oxalates in the raw tissue (168.9 mg/100 g fresh weight (FW)) and was

significantly higher than the other three cultivars (mean 86.5 mg/100 g FW) (Savage and Catherwood 2007). There was no significant difference in gastric-soluble oxalates between Ishikawa-wase, Yamato-wase and the unnamed cultivar. Raw Akame corms contained the highest levels of soluble oxalate after intestinal incubation 134.8 mg/100 g FW. This was significantly different from the other three cultivars, which contained a mean of 66.4 mg intestinal soluble oxalates/100 g FW. Boiling the Japanese taro corms for 40 minutes reduced the level of intestinal soluble oxalates in the cooked tissue to a low level (mean for all the cultivars, 17.7 mg/100 g FW). In addition, the mean moisture content of the boiled corms increased to 83.2 % compared to the mean moisture content of raw tissue (75.7 %). Baking the four cultivars at 180 °C for 40 minutes led to a significant reduction in the moisture content of the tissue (from a mean of 75.7 % moisture content in the fresh tissue to a mean of 50.7 % when baked) and an effective concentration of gastric soluble oxalates in the cooked tissue (overall mean 276.1 mg/100 g FW), while the mean intestinal soluble oxalates rose to 187.2 mg/100 g FW. The results confirm that baked taro corms contain moderate amounts of soluble oxalates. The total gastric soluble oxalates of the four different taro corms were similar to the total oxalate contents determined using hot acid method; however, the in-vitro method used to extract intestinal soluble oxalate appeared to extract more oxalates when compared to the hot water extraction method. Baked taro corms should be avoided by people who have an increased risk of renal calcium oxalate stone formation because they contain high levels of intestinal soluble oxalates. Raw taro had highest oxalate content 156.33 mg/100 g, followed by taro powder 35.67 mg, taro cookies 32.21 mg and taro noodles 29.96 mg (Alcantara et al. 2013). Raw taro also had the highest phytate content 85.47 mg, followed by taro powder 71.97 mg, taro noodles 21.59 mg and taro cookies 12.34 mg. Studies found that boiling effected the highest oxalate reduction, especially in the flour of taro cv. Inimbu (Iwuoha and Kalu 1995). Gelatinisation temperature decreased, and water and oil absorption capacities increased markedly due to steeping, boiling and roasting. Boiling and roasting effected reduction in cold paste viscosity, while an inconsistent trend resulted from steeping.

Other Plant Parts Nutrients/ Phytochemicals

Food value of raw, taro leaves (*Colocasia esculenta*) per 100 g edible portion excluding 40 % midrib stem was reported as follows water 85.66 g, energy 42 kcal (1779 kJ), protein 4.98 g, total lipid (fat) 0.74 g, ash 1.92 g and carbohydrate 6.70 g; total dietary fibre 3.7 g and total sugars 3.01 g; minerals, calcium 107 mg, iron, 2.25 mg, magnesium 45 mg, phosphorus 60 mg, potassium 648 mg, sodium 3 mg, zinc 0.41 mg, copper 0.270 mg, manganese 0.714 mg and Se 0.9 µg; vitamins, vitamin C (total ascorbic acid) 52 mg, thiamine 0.209 mg, riboflavin 0.456 mg, niacin 1.513 mg, pantothenic acid 0.084 mg, vitamin B6 0.146 mg, folate (total) 126 µg, choline (total) 12.8 mg, vitamin A 4825 IU, β-carotene 2895 µg, lutein + zeaxanthin 1932 µg, vitamin E (α-tocopherol) 2.02 mg and vitamin K (phylloquinone) 108.6 µg; lipids, fatty acids (total saturated) 0.151 g, 16:0 (palmitic acid) 0.131 g and 18:0 (stearic acid) 0.020 g; fatty acids (total monounsaturated) 0.060 g, 18:1 undifferentiated (oleic acid) 0.060 g; fatty acids (total polyunsaturate) 0.307 g, 18:2 undifferentiated (linoleic acid) 0.214 g and 18:3 undifferentiated (linolenic acid) 0.093 g; and amino acids, tryptophan 0.048 g, threonine 0.167 g, isoleucine 0.260 g, leucine 0.392 g, lysine 0.246 g, methionine 0.079 g, cystine 0.064 g, phenylalanine 0.195 g, tyrosine 0.178 g, valine 0.256 g, arginine 0.220 g and histidine 0.114 g (USDA-ARS 2014).

Proximate nutrient per 100 g edible portion of taro leaves and petioles reported by Lambert (1982) was, respectively, moisture 79.6, 93.8 %; energy 8,569, 19 cal; carbohydrates 12.2, 4.6 g; protein 4.4, 0.2 g; fat 1.8, 02 g; fibre 3.4, 0.6 g; Ca 32,268, 57 mg; P 78.23 mg; Na 11, 5 mg; K 1,237, 367 mg; Fe 0.84.3, 1.4 mg; vitamin A 20,385, 335 IU; vitamin C 142,8 mg; thiamine 0.1, 0.01 mg; riboflavin 0.33,0.02 mg and niacin 2, 0.2 mg.

The proximate composition (g/100 g DW) of taro leaves was reported as moisture 90.6 g, total energy 396.3 kcal, crude protein 30.7 g, true protein 20.9 g, total lipid 7.7 g, total fibre 30.3 g, total carbohydrate 52.4 g and ash 9.8 g; amino acids (g/16 g nitrogen), threonine 6.2 g, valine 9.4 g, methionine 1.7 g, isoleucine 12.7 g, leucine 12.7 g, phenylalanine 8.0 g, lysine 11.7 g, aspartic acid 13.3 g, serine 5.3 g, glutamic acid 17.2 g, proline 7.5 g, glycine 8.8 g, alanine 10 g, tyrosine 2.8 g, histidine 10.2 g and arginine 9 g; minerals (mg/100 g), Ca 86 mg, P 41 mg, Mg 17 mg, K 18 mg, Na 7 mg, Fe11.7 mg, Mn 25.9 mg, Cu 1.2 mg and Zn 4.2 mg; total oxalic acid 2.41 mg; and soluble oxalic acid 1.13 mg (Ejoh et al. 1996). The proximate composition (g/100 g DW) of taro flowers was reported as moisture 88.8 g, total energy 388.9 kcal, crude protein 14.9 g, true protein 13.1 g, total lipid 5.3 g, total fibre 20.4 g, total carbohydrate 70.4 g and ash 9.4 g; amino acids (g/16 g nitrogen), threonine 4.4 g, valine 7.9 g, methionine 1.1 g, isoleucine 5.7 g, leucine 9 g, phenylalanine 5.3 g, lysine 6.9 g, aspartic acid 10.3 g, serine 4.1 g, glutamic acid 15.6 g, proline 6.5 g, glycine 6.2 g, alanine 9 g, tyrosine 1.7 g, histidine 8.8 g and arginine 7.2 g; minerals (mg/100 g), Ca 86 mg, P 49 mg, Mg 36 mg, K 28 mg, Na 10.4 mg, Fe 30.3 mg, Mn 16.9 mg, Cu 1.9 mg and Zn 8.2 mg; total oxalic acid 1.17 mg; and soluble oxalic acid 0.55 mg (Ejoh et al. 1996).

The leaves of *Colocasia esculenta* contained the highest crude protein value of 307 g/kg DW, and the flowers had 149 g/kg DW (Ejoh et al. 1996). The amino acid profiles in taro flowers and leaves were balanced and comparable to the reference FAO pattern. Ash values were high 98 g/kg in taro leaves with potassium being the principal element. Iron and zinc levels were also high especially in taro flowers (with 303 and 82 mg/kg DW, respectively). Both foods also contained moderate quantities of calcium, phosphorus and magnesium but were poor in manganese and copper.

The mean concentrations (in mg/g) of oxalates, saponins, tannins, alkaloids, lectins, phytates, trypsin inhibitors and cyanogenic glycosides in taro leaves were found to be 13.23, 9.94, 7.38, 6.62, 4.63, 3.41, 2.04 and 0.97, respectively (Enechi et al. 2014). The results revealed that raw taro leaves contained very high concentration of oxalate; moderate concentrations of saponins, tannins, alkaloids, lectins and phytates in order of decreasing concentrations; low concentration of trypsin inhibitors; and very low concentration of cyanogenic glycosides. Young taro leaves contained 589 mg total oxalates/100 g fresh weight (FW), while older taro leaves contained (443 mg total oxalates/100 g FW) (Oscarsson and Savage 2007). Soluble oxalates were 74 % of the total oxalate content of the young and old leaves. The soluble oxalate content of the fresh baked tissue fell to a mean of 59 % for both samples of leaves. Baking the young and old leaves with milk led to a further reduction of the soluble oxalate content in the cooked leaves (mean 21.4 % of the total oxalates).

A red pigment was isolated from taro stalk (called zuiki) and identified it as cyanidin 3-rutinoside (Terasawa et al. 2007). Eight C-glycosylflavones and a flavone *O*-glycoside were isolated from taro leaves and identified as orientin, isoorientin, isovitexin, vicenin-2, orientin 7-*O*-glucoside, isovitexin 4′-*O*-glucoside, vitexin X′-glucoside and luteolin 7-*O*-glucoside (Iwashina et al. 1999). *C. esculenta* leaf was found to have a total antioxidant capacity of 130 mg TEAC/100 g; total polyphenols of 120 mg GAE/100 g; flavonols (mg/100 g) like myricetin 1 mg, quercetin 1 mg and isorhamnetin 1 mg; and carotenoids (mg/100 g) such as α-carotene 0.56 mg and β-carotene 19 mg (Lako et al. 2007). Six *C*-glycosylflavonoids and one *O*-glycosylflavonoid have been isolated from the shoot system of Taumu (*Colocasia esculenta*) (Leong et al. 2010). They were identified as schaftoside (apigenin-6-glucoside-8-C-arabinoside), isoschaftoside (apigenin-6-C-arabinoside-8-C-glucoside), orientin, isovitexin, isoorientin, vitexin and luteolin 7-*O*-sophoroside. Isovitexin was the main compound in water and methanol extracts of the leaf, while schaftoside was the main compound of the water extract of the stem. Taro leaves were found to contain carbohydrate, saponins, tannins and flavonoids such as vitexin, isovitexin, orientin and isoorientin (Vasant et al. 2012).

Forty-one phenolic metabolites (11 hydroxycinnamic acid derivatives and 30 glycosylated flavonoids) were identified in the leaves of two taro varieties (Ferreres et al. 2012). Giant 'white' and 'red' varieties contained, respectively, ca. 14 and 21 % of phenolic acids, 37 and 28 % of flavones mono-C-glycosides, 42 and 43 % of flavones di-C-glycosides, 3 and 4 % of flavones mono-C-(*O*-glycosyl)glycosides and both of them ca. 2 % of flavones di-C-(*O*-glycosyl)glycosides and 2 % of flavones-*O*-glycosides. Luteolin-6-C-hexoside was the compound present in higher amounts in both varieties. The phenolic acids were six caffeic acid derivatives, glucosyl-sinapic acid, caffeic acid, *p*-coumaric acid and two dihydrocaffeoylquinic acid isomers. The flavones mono-C-glycosides identified were luteolin-8-C-hexoside; luteolin-6-C-hexoside; apigenin-8-C-hexoside; apigenin-6-C-hexoside; chrysoeriol-8-C-hexoside; and chrysoeriol-6-C-hexoside. The flavones di-C-glycosides identified were luteolin-6,8-di-C-hexoside; luteolin-6-C-hexoside-8-C-pentoside; apigenin-6,8-di-C-hexoside; luteolin-6-C-hexoside-8-C-pentoside; luteolin-6-C-pentoside-8-C-hexoside; apigenin-6-C-pentoside-8-C-hexoside; luteolin-6-C-pentoside-8-C-hexoside; apigenin-6-C-pentoside-8-C-pentoside; chrysoeriol-6-C-hexoside-8-C-pentoside; diomestin-6-C-hexoside-8-C-pentoside; and diomestin-6-C-hexoside-8-C-pentoside. The flavones mono-C-(*O*-glycosyl)glycosides detected were luteolin-6-C-(6-*O*-hexosyl)hexoside; 16 apigenin-6-C-(6-*O*-hexosyl)hexoside; luteolin-6-C-(2-*O*-pentosyl)hexoside; and apigenin-8-C-(2-*O*-penytosyl)hexoside. The flavones di-C-glycoside-*O*-glycosylated found were apigenin-6-C-pentoside-8-C-hexoside-7-*O*->hexoside; luteolin-6-C-(3-*O*-hexosyl)hexoside-8-C-pentoside; apigenin-6-C-pentoside-8-C-(2-*O*-hexosyl)hexoside; and apigenin-6-C-(2-*O*-hexosyl) hexoside-8-pentoside. The flavones *O*-glycosides identified were luteolin-7-*O*-rhamnosyl(1→2) hexoside; chrysoeriol-7-*O*-hexoside; and chrysoeriol-7-*O*-rhamnosyl(1→6)hexoside.

The following chemicals were identified in taro leaf: cyclohexanol, 2-methyl-5-(1-methylethyl)-, [1S- (1α, 2β, 5β)]- (54.73 %), 4H-pyran-4-one, 2,3-dihydro-3,5—dihydroxy-6-methyl- (9 %), 3,5-di-tert-butyl-4-trimethylsiloxytoluene (8.12 %), 2-propanone, 1-hydroxy- (7.37 %), 9,11-octadecadienoic acid, methyl ester, (*E*, *E*)- (5.79 %), hexadecanoic acid, methyl ester (4.28 %), formic acid, 2-propenyl ester (3 %, 21 %), megastigmatrienone (2.84 %) and unidentified (4.66 %) (Lee et al. 2011).

The following chemicals were identified in taro stem (shoot): acetic acid (24.70 %), 4H-pyran-4-one, 2,3-dihydro-3,5—dihydroxy-6-methyl- (19.25 %), propanoic acid (11.83 %), 2-furancarboxaldehyde,5-(hydroxymethyl)- (6.82 %), 9,12-octadecadienoic acid, methyl ester, (*E*,*E*)- (3.64 %), 9,12,15-octadecatrienoic acid, methyl ester, (Z,Z,Z)- (5.37 %), 2-furanmethanol (4.74 %), butanoic acid, 2-methyl-3-oxo-, ethyl ester (4.18 %), cyclopentanol (2.69 %), 2,2′-bioxirane (2.33 %), propanoic acid, 2-oxo-,methyl ester (2.26 %), butanoic acid,4-hydroxy- (2.11 %) and unidentified (7.38 %) (Lee et al. 2011).

Ferredoxin with molecular weight of 120,000 was isolated and purified from taro (Rao 1969). The protein contained two atoms of iron, two molecules of labile sulfide and five cysteinyl groups per molecule. The amino acid composition is $Lys_{4–5}$, His_1, Ang_1, Cys_5, Asx_{10}, Thr_6, Ser_8, Glx_{16}, Pro_4, $Gly_{9–10}$, Ala_7, Val_{10}, Ile_4, Leu_6, Tyr_4, Phe_2 and Trp_1. The amino and carboxy terminals of the protein were alanine. Taro ferredoxin was found to consist of a single polypeptide chain of 97 amino acids (Rao and Matsubara 1970). A comparison of structures of five chloroplast ferredoxins showed 61 % identity in their sequences. The amino acid sequences of ferredoxins (Fd A and Fd B) from Japanese taro (*Colocasia esculenta*) consisted of single polypeptide chains of 98 residues, and both ferredoxins had molecular masses of 10,700 and 10,500, respectively (Sakai et al. 1994). There was a 92 % homology between the sequences of the isoproteins (Fd A and Fd B). Two ferredoxin isoproteins from Hawaiian taro (*Colocasia esculenta*) were also isolated, and their N-terminal sequences were determined to be identical to those of Japanese taro.

Enzymes found in taro included aconitase, aldolase, diaphorase, phosphoglucomutase, malate dehydrogenase, phosphoglucose isomerase, isocitrate dehydrogenase, 6-phosphogluconate dehydrogenase, malic enzyme, shikimate dehydrogenase and alcohol dehydrogenase (Lebot and Aradhya 1991). A comparison of structures of five chloroplast ferredoxins showed 61 % identity in their sequences. pCeMT, a putative metallothionein was isolated from *Colocasia esculenta* plant (Kim et al. 2013). The results suggested that pCeMT could play an important role in the protection of plant cells from oxidative stress by reactive oxygen species (ROS) scavenging and in the detoxification of free metals by metal binding, leading to improved plant metal tolerance.

Taro leaves also contain useful amounts of calcium, phosphorus and iron. It also provides fibre, which is needed to make the intestines and bowels work properly. Corms and cormels are rich in starch, minerals and vitamins; the flesh is mealy to smooth and usually has a somewhat nutty flavour. The starch grains are very small and consist of a mixture of two types, one 1–1.5 μm and the other 3–4 μm in diameter. For this reason, taros are easily digested. Taro starch has relatively high amylose content, high short-to-long-chain ratio and long average chain length of long-chain fraction of amylopectin and displayed high elasticity and strong gel during heating. The corms are also an excellent source of energy, which the body needs to stay active. They are rich in mucilage, which on hydrolysis yields eight sugars, the predominant ones being D-galactose and l-arabinose.

Antioxidant Activity

Raw tannin exhibited antioxidant activity (% lipid peroxidation) of 74.68 % and contained phenols (mg/100 g expressed as g catechin eq./g) 34.83 mg, tannins (mg/100 g expressed as vanillin eq./g 32.24 mg, flavonoids 9 mg/10 g expressed as mg gallic acid eq./g) 28.56 mg and saponins (mg/100 g) 14.22 mg (Alcantara et al. 2013). Taro powder had 81.77 % antioxidant activity, 78.33 mg phenols, 32.24 mg tannins, 64.23 mg flavonoids and 26.96 mg saponins. Taro noodles had 65.91 % antioxidant activity, 16.27 mg phenols, 0 mg tannins, 2.96 mg flavonoids and 5.01 mg saponins. Taro cookies had 28.00 % antioxidant activity, 3.68 mg phenols, 0 mg tannins, 0.90 mg flavonoids and 2.73 mg saponins. The higher the per cent lipid peroxidation, the lower the antioxidant activity.

The radical scavenging activity of purified taro stalk (zuiki) anthocyanin was 114 mg equivalent to BHT/g (Terawasa et al. 2007). About half of the anthocyanin in fresh zuiki was washed out by boiling, and the radical scavenging activity of zuiki was markedly reduced.

The presence of catechol moiety in the B-ring of isoorientin, orientin and luteolin 7-*O*-sophoroside, isolated from taro shoot system showed strong antioxidant activity with different mechanisms of action in DPPH radical scavenging, β-carotene bleaching and superoxide radical inhibition assays (Leong et al. 2010). Methanol extract of taro leaf showed higher DPPH radical scavenging activity than water extract, while the opposite was observed for the stem. The amount of dry weight matter extract of water extracts was higher than methanol for both the leaf and the stem parts. Isovitexin was the main compound in water and methanol extracts of the leaf, while schaftoside was the main compound of the water extract of the stem. The results suggested the potential of the leaf of Taumu as a source of dietary antioxidant. *C. esculenta* stem extract exhibited the highest DPPH scavenging activity with IC_{50} 0.125 ppt (parts per thousand) compared to the corm and leaf (0.28 ppt), and the corm extract (4.8 ppt) was the lowest (Lee et al. 2011).

Under arsenic stress (high concentration), an increase in catalase, peroxidase, few nonenzymatic antioxidants and an induction of few stress-induced protein were observed, along with some anatomical changes in taro roots. The increase in antioxidant stress enzyme activities in response to arsenic exposure may be taken as evidence for an enhanced detoxification capacity of *C. esculentum* towards reactive oxygen species (and derivatives) that might be generated in the stressed plants (Patel et al. 2012).

Antidiabetic Activity

Dasheen extract or commercial linamarin significantly increased the activities of intestinal disaccharidases compared to the streptozotocin-induced diabetic rats fed with normal diet (Grindley et al. 2002). In the upper segment of the intestine, yam or dasheen extract or commercial linamarin supplementation increased the activity of Na^+/K^+ ATPase activity above normal. This enzyme in the lower segment of the intestine was significantly reduced in diabetic rats compared to normal rats. These observations indicated the hypoglycaemic property of cyanoglucoside extract from dasheen and to a lesser extent yam. Experimental studies showed that oral administration of petroleum ether, chloroform, aqueous and ethanolic extracts of taro leaves at a dose of 500 mg/kg body weight significantly exhibited antidiabetic activity in streptozotocin (STZ)-induced diabetic rats by reducing and normalising the elevated fasting blood glucose levels as compared to those of STZ control group (Tripathi and Koli 2013). The ethanol and aqueous leaf extracts were most active. In another study, administration of taro and plantain (*Musa paradisiaca*) feeds for 21 days to the diabetic rats of groups 4 and 5 resulted in 58.75 % and 38.13 % decreases in hyperglycaemia and amelioration of their elevated urinary protein, glucose, specific gravity and relative kidney weights (Eleazu et al. 2013). The diabetic rats administered with taro-incorporated feeds had 2.71 % and 19.52 % increases in weight and growth rates, the diabetic rats administered with unripe plantain-incorporated feeds had 5.12 % and 29.52 % decreases in weight and growth rates while the diabetic control rats had 28.69, 29.46, 248.9 and 250.14 % decreases in weights and growth rates. The taro-incorporated feeds contained higher antioxidants, minerals and phytochemicals except alkaloids than unripe plantain feed.

Dasheen with a glycaemic index (GI) of 77 was deemed a higher GI food than eddoes with GI of 66 (Ramdath et al. 2004). In a study of ten healthy subjects aged between 20 and 30 years, consumption of brown rice elicited the highest postprandial glucose and insulin responses, followed by taro, adlay, yam and mung bean noodles, which produced the lowest (Lin et al. 2010). Among the five starchy foods, brown rice evoked the highest glycaemic index (GI) and glycaemic load (GL) at 82 and 18, followed by taro (69 and 12), adlay (55 and 10), yam (52 and 9) and mung bean noodles (28 and 7), respectively. The insulinaemic index (II) values of the test foods corresponded with GI values. Similarly, brown rice gave the highest II at 81, followed by taro (73), adlay (67), yam (64) and mung bean noodles (38). All five starchy foods had lower GI, GL and II than reference bread. The GI, GL and II values of starchy foods provide important information for people to manage their diet and could be useful for the prevention of lifestyle-related diseases such as diabetes mellitus.

The activity of taro α-amylase inhibitor named esculentamin was essentially stable to boiling for 3 hours (pH 7.0), to a pH range of 2.0–12.0 (at 4 °C) and to 6 M guanidine hydrochloride and 8 M urea (Seltzer and Strumeyer 1990). 'Bifunctional' inhibitory activity towards both α-amylase and proteases was not observed with esculentamin (i.e. it did not inhibit the several proteases tested, viz., trypsin and subtilisin). Two taro α-amylase inhibitors, isolated from corms, inactivated α-amylases of animal origin but had no effect on fungal amylase (McEwan et al. 2010). Inhibitor A-1 also exhibited activity towards plant amylases, while inhibitor B-2 has no activity on plant amylases. Inhibitor A-1 was the most active against human salivary amylase at pH 6. Inhibitor A-1 was completely destroyed at temperatures above 50°C, while inhibitor B-2 was stable up to 70 °C. In a recent study, purified α-amylase inhibitor from *Colocasia* corm was found to be heat stable and retained 81.50 % activity at 70 °C temperature to have pH optima of 6.9 (Kumari et al. 2012). It was found to have inhibitory activity against α-amylases extracted from the larvae of several insects and to inhibit the activity of human salivary α-amylase. It also had inhibitory activity against potato α-amylases and reduced sugar content in treated potato slices. Inhibitory activity of α-amylase inhibitor against mamma-

lian amylases could suggest its potential in treatment of diabetes and cure of nutritional problems, which result in obesity. The α-amylase inhibitors of taro were almost totally inactivated during oven drying of the chips at 90 and 100 °C for 24 hours (Rekha and Padmaja 2002). Cooking by boiling the corms resulted in retention of 11–16 % of the inhibitor in taro. Flour prepared from the corms retained only trivial amounts of the inhibitor. Microwave baking was a better method for inactivation of amylase inhibitors.

Ethanolic taro leaf extract (400 mg/kg) showed antihyperglycaemic activity in alloxan-induced diabetic rats (Kumawat et al. 2010). Taro leaf extract was found to have significant blood glucose-lowering effect and prevented weight loss. No mortality was observed with administration of the extract up to 500 mg/kg.

The expected glycaemic index (eGI) of taro starch and taro-resistant starch was determined as 60.6 and 51.9, respectively, and the decrease in the glycaemic index of taro-resistant starch was found to be statistically significant (Simsek and El 2012). The in-vitro binding of bile acids by taro starch and taro-resistant starch relative to cholesterol-decreasing drug cholestyramine were 5.2 % and 7.6 %, respectively.

Anxiolytic Activity

The anxiolytic activity of hydroalcoholic taro leaf HECE (100, 200 and 400 mg/kg) per os (p.o.) was characterised by increased time spent by adult Wistar rats and number of entries in open arms in the elevated plus maze paradigm as compared to control group (Kalariya et al. 2010). Taro leaf extract (100, 200 and 400 mg/kg, p.o.) showed dose-dependent significant reduction in duration of immobility in the behaviour despair test. At doses of 50 and 100 mg/kg, i.p., it produced a significant reduction in motor coordination of Swiss albino mice and prolongation of thiopental-induced sleeping time. The phytochemical screening revealed the presence of flavonoids, β-sitosterol and steroids in the extract.

Antihyperlipidaemic/ Antihyperchlosterolaemic Activities

Colocasia esculenta showed the highest inhibition (55 % inhibition at 300 μg/mL) of human lanosterol synthase, a key enzyme involved in cholesterol biosynthesis (Sakano et al. 2005). A purified taro fraction afforded three monogalactosyldiacylglycerols (MGDG 1–3) and five digalactosyldiacylglycerols (DGDG 1–4) that showed 28–67 % inhibitory activities at the concentration 300 μg/mL. DGDG-4 was a mixture of digalactosyldiacylglycerols with 'one linoleate and one oleate' and 'one linoleate and one palmitate' with the ratio of 1:5. In another study, digalactosyldiacylglycerol (DGDG) and monogalactocyldiacylglycerol (MGDG) were identified as anti-hyperlipidaemia active components in *Colocasia esculenta* (Tanaka et al. 2005). DGDG with two myristoyl groups at both sn-1 and sn-2 positions and with an oleoyl group at the sn-1 position showed the most potent inhibitory activity on human lanosterol synthase.

Feeding of arabinogalactan mucilage from taro corms at a dose of 4 mg/100 g body weight daily for 8 weeks exerted a hypolipidaemic effect in rats (Boban et al. 2006). The mucilage decreased the lipid levels both in the serum and tissues. There was a decrease in the synthesis and secretion of apo B-containing lipoproteins, mainly VLDL, by hepatocytes isolated from mucilage-fed rats when compared to control.

Antihypertensive Activity

Administration of aqueous taro leaf extract in renal artery-occluded hypertensive rats at concentrations of 100, 200 and 400 mg/Kg/day, p.o., and in noradrenalin-induced hypertension rats at concentrations of 20 and 40 mg/Kg, i.v., produced significant antihypertensive effects (Vasant et al. 2012). The leaf extract (400 mg/Kg, p.o.) showed positive diuretic activity at 5 hours. The antihypertensive and weak diuretic activity of the extract may be attributed due to acetylcholine inhibitory, vasodilatory, β-blocking and/ or Ca^{2+}

channel-blocking activities, which were reported for the phytoconstituents, specifically flavonoids such as vitexin, isovitexin, orientin and isoorientin present in the leaves.

Anticancer Activity

Soluble extracts of poi, a starchy paste made from the taro corm, at 25 % concentration exerted the greatest suppression of YYT colon cancer growth via apoptosis (Brown et al. 2005). Poi enhanced the proliferation of normal mouse splenocyte control cells, suggesting that poi was not simply toxic to all cells but even had a positive immunostimulatory role. By flow cytometry, T cells (CD4+ and CD8+) were predominantly activated by the poi. A dimeric haemagglutinin isolated from taro corm exhibited slight antitumour activity towards hepatoma HepG2 cells and weak mitogenic activity towards murine splenocytes (Chan et al. 2010). It induced the expression of the cytokines interleukin-1 beta, interleukin-2, interferon-gamma and tumour necrosis factor-alpha. However, it was devoid of antifungal activity towards a number of fungal species.

A water-soluble extract of taro (TE) potently inhibited lung-colonising ability and spontaneous metastasis from mammary gland-implanted tumours, in a murine model of highly metastatic oestrogen receptor, progesterone receptor and HER-2-/neu-negative breast cancer (Kundu et al. 2012). TE modestly inhibited the proliferation of some, but not all, breast and prostate cancer cell lines. TE treatment also inhibited prostaglandin E2 (PGE2) synthesis and downregulated cyclooxygenase 1 and 2 mRNA expression. The active metastatic compound was isolated and had a native size of approximately 25 kDa with two fragments of nearly equal size. The N-terminal amino acid sequencing of both fragments revealed that the active compound was highly related to three taro proteins: 12-kDa storage protein, tarin and taro lectin with similar amino acid sequence and a carbohydrate-binding domain.

The administration of Taro-4-I (taro polysaccharide) significantly inhibited the lung metastasis of B16-BL6 melanoma cells (Park et al. 2013). However, the group treated with 50 μg/mouse Taro-4-I had a significantly lower number of tumours compared to the group injected with 500 μg/mouse Taro-4-I. Also, treatment of peritoneal macrophages with Taro-4-I significantly increased the production of interleukin (IL)-6 and tumour necrosis factor-α (TNF-α) in a dose-dependent manner. However, IL-12 production showed maximal activity at 56 μg/mL and subsequently decreased.

The extracts from edible parts of *Colocasia esculenta* and the skin of taro showed markedly greater inhibitory effects on adult T-cell human leukaemia Su9T01 cell line than genistein (Kai et al. 2011). At concentration of 20 and 30 μg/mL, corm and stem extract inhibited 30 % of human breast adenocarcinoma MCF-7 cancer cells, respectively. Leaf extract showed no anticancer activity (Lee et al. 2011).

Three unlignified cell wall (dietary) preparations from taro edible parts exhibited ability to adsorb the hydrophobic environmental mutagen 1,8-dinitropyrene (Ferguson et al. 1992). The greatest adsorption occurred with cell walls from leaf blade, followed by petiole and corm walls, although the differences were not major. The amount of adsorption was intermediate between the low adsorption previously found with unlignified dicotyledon walls (from the flesh of potato tubers and immature cabbage leaves) and the much higher adsorption found with unlignified walls from monocotyledons of the grass and cereal family (Poaceae) (from leaves of seedling Italian ryegrass). The adsorption of carcinogenic mutagens by dietary fibres may assist to protect against colorectal cancer.

Hepatoprotective Activity

Taro leaf juice prevented the occurrence of lipid peroxidative reactions in the rat liver slices caused by the presence of free radicals generated by the hepatotoxins CCl_4 and acetaminophen (Patil and Ageely 2011b). Simultaneously marked elevations and prevention of depletion of total tissue glutathione were observed in the

presence of taro leaf juice. Taro leaf juice also showed antihepatotoxic and hepatoprotective efficacy against hepatotoxicity induced by CCl_4 and paracetamol causing oxidative stress and damage to various cell organelles consequently resulting in injury to the hepatocytes (Patil and Ageely 2011a). Taro leaf juice significantly reduced the leakage of marker enzymes AST, ALT and ALP in the medium indicating hepatocyte integrity.

Wound Healing Activity

C. esculenta wound healing potential could be attributed, at least in part, to the protection of the wound site against oxidative/nitrosative damage and prevention of hyaluronic acid degradation (Gonçalves et al. 2013). They found that *C. esculenta* varieties were able to scavenge several oxidant species and to inhibit hyaluronidase, but data suggested that metabolites other than phenolics were involved.

Mitogenic and Haemagglutination Activities

The haemagglutinating activity of the dimeric haemagglutinin isolated from taro corms could not be inhibited by simple sugars and was stable after exposure for 30 minutes to temperatures up to 40 °C and to ambient pH in the range of pH 2 to pH 13 (Chan et al. 2010). The activity decreased progressively when the ambient temperature was raised from 40 to 100 °C. Tarin, a storage lectin from taro, exhibited both agglutinating activity against hamster erythrocytes and mitogenic activity in-vitro and in-vivo towards mouse splenocytes (Pereira et al. 2014). Optimum cellular proliferation in-vitro was achieved by 625 ng of the crude extract or 500 ng of the purified tarin. Total mouse splenocyte proliferation measured after 5 days of intraperitoneal inoculation of purified tarin was increased 3.3-fold in comparison to the control group. Half of the proliferating cells were identified as B lymphocytes by flow cytometry. The lectin *Colocasia esculenta* agglutinin (CEA) was purified from taro corms and was found to be specific towards N-acetyl-D-LACTOSAMINE (LacNac), a disaccharide and asialofetuin, a desialylated serum glycoprotein in haemagglutination inhibition assay (Thakur et al. 2013).

Taro alpha-D-galactosidase was found to convert B into group O red cells (Chien and Lin-Chu 1991). The blood group-converting activity was demonstrated by hemolysis and haemagglutination studies. At a final enzyme concentration of 30 units/mL in the incubation mixture, the conversion of group B into group O activity was completed within 2 hours, without apparent changes in the shape of the red cells. The recombinant taro α-Gal not only hydrolysed the α1→4-linked galactosyl residues, which accumulated in the tissues from patients with Fabry disease, but also hydrolysed the α1→3-linked galactoside of B red blood cells (Chern et al. 2012).

Antimelanogenic Activity

Among the compound isolated from taro corm skin, *cis*-grossamide K (2), isoamericanol A (3), americanol A (4), 2-hydroxy-3,2′-dimethoxy-4′-(2,3-epoxy-1-hydroxypropyl)-5-(3-hydroxy-1-propenyl)biphenyl (5) and (-)-pinoresinol (6) showed inhibitory effects on melanin production (Kim et al. 2010b). Compounds 2, 5 and 6 exerted a particularly strong antimelanogenic activity on the cells without high cell toxicity (IC_{50} = 54.24, 53.49 and 56.26 μM and LD_{50} = 163.60, 110.23 and >500 μM, respectively). Of the fatty acid derivatives isolated from taro corm peel, 12,13-epoxyoctadec-9-(*Z*)-enoic acid (7) dose-dependently inhibited melanin content with significant cell toxicity (Kim et al. 2010a). At 100 μm concentration, compound 7 strongly inhibited melanin biosynthesis with an effective ratio of 35.43 in comparison to control. Monoglyceride 1-*O*-(octanoyl) glycerol (6) was also active in inhibiting melanin content at 10 μM but exhibited cell toxicity at higher concentrations. Compound 12,13-epoxyoctadec-6(*Z*),9(*Z*)-dienoic acid (10) containing an epoxy group slightly reduced the melanin content but displayed

toxicity at higher concentrations. It was concluded that the fatty acid derivatives 6, 7 and 10 could be used as effective depigmenting agents and for cosmetic development.

Anti-inflammatory Activity

An ethanolic extract of *C. esculenta* leaves produced significant anti-inflammatory activity when compared with the standard and untreated control (Shah et al. 2007). The ethanolic extract (100 mg/kg, p.o.) inhibited carrageenan-induced rat paw oedema. It also showed an inhibitory effect on leucocyte migration and a reduction on the pleural exudates as well as reduction on the granuloma weight in the cotton pellet granuloma method. The ethanolic taro leaf extract (100 mg/kg, p.o.) inhibited carrageenan-induced rat paw oedema (Biren et al. 2007). It also showed an inhibitory effect on leucocyte migration and a reduction on the pleural exudates as well as reduction on the granuloma weight in the cotton pellet granuloma method. The results indicated that the ethanolic extract produced significant anti-inflammatory activity.

Antimicrobial Activity

Aqueous taro leaf extract exhibited antibacterial activity in-vitro against *Vibrio alginolyticus*, *V. cholerae*, *V. harveyi*, *V. parahaemolyticus* and *V. vulnificus* but not the stem and corm extracts (Lee et al. 2004). Aqueous taro leaf extract exhibited maximum activity in-vitro against *Streptococcus mutans* among the selected microbial strains (Singh et al. 2011). The antimicrobial MIC values of different parts of *C. esculenta* ranged from 7.81 to 500 mg/L in which the MIC of the corm extract against *Edwardsiella tarda Escherichia coli*, *Flavobacterium sp*., *Pseudomonas aeruginosa* and *Vibrio cholera* was 15.6 mg/L and *Klebsiella* sp., *Aeromonas hydrophila* and *Vibrio alginolyticus* was 31.4 mg/L, and it was able to control the growth of *Salmonella* sp. and *Vibrio parahaemolyticus* at 125 mg/L (Lee et al. 2011). The MIC values of the shoot against *Edwardsiella tarda Escherichia coli*, *Flavobacterium sp*., *Pseudomonas aeruginosa* and *Vibrio cholerae* was 7.81 mg/L and *Klebsiella* sp., *Aeromonas hydrophila* and *Vibrio alginolyticus* was 15.61 mg/L, and it was able to control the growth of *Salmonella* sp. and *Vibrio parahaemolyticus* at 62.5 mg/L. At concentration of 62.5 mg/L, the leaf extract was found to inhibit the growth of *Edwardsiella tarda Escherichia coli*, *Flavobacterium* sp., *Pseudomonas aeruginosa* and *Vibrio cholera*, whereas at 125 mg/L, *Klebsiella* sp., *Aeromonas hydrophila* and *Vibrio alginolyticus* failed to grow. Taro plant extract was able to control the growth of *Salmonella* sp. and *Vibrio parahaemolyticus* at 500 mg/L.

Probiotic Activity

Researchers in Hawaii found that poi, a pasty starch made from the cooked, mashed corm of the taro, contained significantly more of lactic acid-producing bacteria *Lactococcus lactis* (95 %) and *Lactobacilli* (5 %) bacteria per gram than yogurt and could have potential use as a probiotic albeit more research needed to be conducted (Brown and Valiere 2004). A probiotic is defined by FAO/WHO as 'live microorganisms which when administered in adequate amounts confer a health benefit to the host'. Documented evidence suggested that poi showed promise for use in infants with allergies or failure to thrive (Derstine and Rada 1952).

Poi for Allergic People/Infants

According to the survey of doctors and paediatricians, poi's most popular therapeutic uses were in convalescent or soft diets (90 %), elderly persons with no teeth (90 %), malnutrition (70 %), cereal allergies (60 %), gastric ulcers (40 %) and hyperacidity (40 %) (Derstine and Rada (1952). The idea that fermentation of poi reduces the bacterial load of the fresh product, and improves digestibility, was raised, but research was not available to confirm it, and the physicians surveyed lacked knowledge of this aspect. Glaser et al. (1967)

found poi to be a practical substitute for the true cereals in the feeding of full-term and premature infants and for feeding at any age in patients allergic to the true cereals. It should also be invaluable in the feeding of potentially allergic infants for the prophylaxis of allergy to cereals and in the treatment of celiac disease as it contained no gluten. They asserted that its use in cystic fibrosis as well as gastrointestinal disturbances of other origin merited full investigation.

Anthelmintic Activity

Aqueous and ethanolic taro leaf extract exhibited anthelmintic activity against earthworm *Pheretima posthuma* in a dose-dependent manner giving the shortest time of paralysis (P) and death (D) at 50 mg/mL concentration (Kubde et al. 2010). The ethanolic taro leaf extract caused paralysis of 16 minutes and time of death of 42 minutes, while water extract revealed paralysis of 31.25 minutes and death of 60.34 minutes against the earthworm. The reference drug piperazine citrate showed the same results at 12 and 26 minutes, respectively. Phytochemical screening of the crude extracts revealed the presence of riboflavin, niacin, oxalic acid, calcium oxalate and sapotoxin; anthocyanins perlargonidin 3-glucoside, cyanidin 3-rhamnoside and cyanidin 3-glucoside; and saponins.

Drug Delivery Activity

Taro corms mucilage/hydroxypropylmethylcellulose (HPMC)-based transdermal patch (matrix type) was found to be an efficient device for the delivery of the drug diltiazem hydrochloride (Sarkar et al. 2014). In-vitro drug release time of mucilage/HPMC-based transdermal patches was prolonged with increasing mucilage concentration in the formulation.

Effect on Growth

Feeding of weanling Wistar rats with different accessions (with different morphological traits) of cooked taro-based diets for 28 days was found to enhance growth performance (Lewu et al. 2011) Taro-based diet accessions UFCe1, UFCe2, UFCe4, UFCe5 and UFCe6 increased the average weekly water intake, feed consumption, total body weight, liver–body weight ratio and kidney–body weight ratio of the animals; while UFCe3 and UFCe7 decreased these measures. All the accessions of taro-based diets did not significantly alter the serum levels of albumin, globulin, inorganic phosphorus, calcium, magnesium and uric acid of the animals (Lewu et al. 2010). All the accessions of cooked *Colocasia esculenta* (taro)-based diets (UFCe1–UFCe7) decreased the serum alkaline phosphatase activity; γ-glutamyl transferase activity was increased in weanling rats, Overall, the results revealed that all the accessions of C. *esculenta* produced selective effects on the hepatic and renal functional indices of the weanling rats. The highest alterations were produced by UFCe4, whereas the least was from UFCe2. These alterations may have consequential effects on the normal functioning of the liver and kidney of the animals.

Removal of Antinutrient Factors

The acridity of the leaves, petioles and tubers is due to raphides, but this usually had been reported to disappear on boiling or cooking (Green well 1947; Murai et al. 1958). Taro contained an irritant preventing its corm from being eaten raw or incompletely cooked; the irritation could be removed by prolonged baking or boiling (Moy et al. 1979). Results suggested that the acridity of taro was not caused solely by the calcium oxalate raphides but was also associated with a boiling water and ethanol labile factor. Separation of the idioblasts reduced the acridity. Extraction with ethanol either removed the factor or rendered the cell's ability to deliver the factor useless. In nine taro cultivars, total oxalate contents ranged from 43 to 156 mg/100 g fresh weight (FW), and soluble oxalate contents ranged from 19 to 87 mg/100 g FW (Huang and Tanudjaja 1992). Insoluble oxalate accounted for 29.35–73.97 % of the total oxalate contents in the taro corms.

Taro tuber was the most potent source of anti-trypsin and anti-chymotrypsin activities (Prathiba et al. 1995). When tubers were processed by pressure cooking, there was significant reduction/complete elimination in inhibitory activity. Partial retention of inhibition was observed in the case of chymotrypsin inhibitor and trypsin inhibitor in taro. Taro corms contained antinutrients in the form of trypsin and chymotrypsin inhibitors which could be partially or wholly eliminated by thermal inactivation (Kiran and Padmaja 2003). Trypsin inhibitors (TI) in taro corms could be inactivated by thermal processing. Heating at 100 °C led to rapid inactivation of TI; only 3–10 % of TI were retained in taro cultivars. More effective inactivation of TI of taro could be obtained through microwave baking. Flour prepared from taro was devoid of TI activity.

The Akame cultivar contained the highest level of total oxalate (171.4 mg/100 g fresh weight (FW)) in the raw corm tissue and was significantly higher than the other three Japanese cultivars (Ishikawa-wase, Yamato-wase and an unnamed cultivar) (Catherwood et al. 2007). The raw tissue of the four cultivars contained a mean of 60.6 % soluble oxalates; boiling reduced the level of soluble oxalate in the cooked tissue to below detectable levels as soluble oxalates leached into the cooking water. Baking led to a significant reduction in the moisture content of the taro concentrating oxalates in the cooked tissue (overall mean, 229.0 mg/100 g FW).

The soluble oxalate content of the raw taro leaves was 236.10 mg oxalate/100 g wet matter (WM) (Savage and Duboi 2006). Soaking the raw leaves in water for 30 minutes marginally reduced the soluble oxalate content by leaching into the tap water. Soaking for 18 hours resulted in a 26 % reduction in the soluble oxalate content of the raw leaves. Boiling the taro leaves resulted in a 36 % loss of soluble oxalates, while the soluble oxalate content of baked tissue was very similar to the raw tissue. The mean insoluble oxalate content of the raw, boiled and baked tissue was 226.28 mg oxalate/100 g WM. Overall, boiling taro leaves was an effective way of reducing the soluble oxalate content of the cooked tissue. Wilting of taro leaves and petioles for 18 hours resulted in an overall 5.9 % reduction of soluble oxalates, and washing in cold water for 5 minutes resulted in a 26.2 % reduction in soluble oxalate content (Du et al. 2013). Soaking the petioles and the petioles and leaves for 10 hours in water kept at 36–38 °C resulted in a mean 69.5 % reduction in the soluble oxalate content of the raw tissues. Boiling for 60 minutes was the most effective way to reduce the soluble oxalate levels in the cooked tissue. A mean 84.2 % reduction in soluble oxalate in the petioles and the petioles and leaves was achieved after boiling for 60 minutes, while mean reductions of 62.1 % were achieved when both materials were boiled for only 10 minutes.

Oke and Bolarinwa (2012) found that fermentation of taro flour effected a significant reduction in oxalate level (58–65 %) depending on the fermentation period. The amylose content was higher in 48-hour-fermented flour (55.52 %) than in 24-hour-fermented flour (54.55 %). Pasting (gelatinisation) temperature decreased, and water absorption capacity increased markedly due to fermentation. Studies by Olajide et al. (2011) found that contents of antinutrient factors such as tannins, phytate, oxalate, saponin and hydrocyanide (HCN) in taro corms were significantly reduced by processing methods with raw sun-dried taro recording the highest value. Fermentation had the highest percentage reductive values of 42.86, 69.23, 95.05, 73.58 and 57.91 % in condensed tannins, hydrolysable tannins, phytate, oxalate and HCN, respectively, while the highest percentage reduction of 48.39 % in saponin was obtained in cooked corms. There were no activities detected for trypsin inhibitors in all the processed forms of taro corms. Crude protein was significantly highest in fermented corms and significantly lowest in cooked corms. Crude fibre significantly decreased by the processing methods with the highest values obtained in raw and soaked corms.

Toxicity Issues

A case report of an otherwise healthy 2-year-old boy with a history of pica, associated with iron

deficiency anaemia, was reported in conjunction with earlier ingestion of *C. esculenta* leaf (Mihailidou et al. 2002). He had an acute episode of sialorrhoea, difficulty in speaking, dysphagia and repeated swallowing movements. An uncertain episode of a brief-duration still gaze was also reported.

Traditional Medicinal Uses

The leaf juice of the plant is styptic, stimulant and rubefacient and is useful in internal haemorrhages, otalgia, adenitis and buboes; the juice of the corm is laxative, demulcent and anodyne (Warrier et al. 1993). Medicinal taro varieties were used to treat or cure human ailments.

According to Watt (2014) in India, the pressed juice of the petioles is styptic and may be used to arrest arterial haemorrhage. It is occasionally used in treating earache and otorrhea and also an external stimulant and rubefacient. The juice of the corm is used in cases of alopecia. Internally, it acts as a laxative and is used in cases of piles and congestion of the portal system and also an antidote to the stings of wasps, snakes and other insects. In Punjab and in Cashmere, the roots are used in catarrh and colic (Kirtikar and Basu 1975; Chopra et al. 1986; Nadkarni 2001). The ash of the tuber mixed with honey is applied for aphthae in the mouth. Stems are sometimes used medicinally, notably in the treatment of snakebites. The heated tubers are locally applied to painful parts. Taro corm juices are widely used for traditional treatment of body ache and baldness (Prajapati et al. 2011). *Colocasia esculenta* was one of the several plants used to treat diabetes mellitus by the rural community of Dhemaji district of Assam, Northeast India (Tarak et al. 2011).

In Hawaii, the raw juice of taro is given to drink, mixed with sugar, as a febrifuge. In Asia and Africa, this species is also used in traditional medicine to treat arterial hypertension, liver problems, ulcers, snakebites and rheumatism (Onwueme 1999; Safo-Kantaka 2004). In Gabon, raspings from the corm are applied as a poultice to maturate boils and to treat snakebites and rheumatism. In Mauritius, boiled young leaves are consumed to treat arterial hypertension and liver affections, and the juice is applied externally to treat eczema. In Madagascar, the corms are employed to treat boils and ulcers.

Other Uses

Corms and cormels are rich in mucilage and can be utilised in the paper industry or possibly in medicinal tablet manufacture. Spray drying conditions used produced spherical aggregates of taro starch that presented physicochemical and functional characteristics with potential for encapsulation of substances (Gonzalez-Soto et al. 2011).

Because of its small granular size, taro starch has been considered a good filling agent for biodegradable polyethylene film (Griffin and Wang 1983) and as a fat substitute. When taro starch is used in the production of plastics in an appropriate formulation, the result can be a useful acceleration of the biodegradability of the parent polymer. High fructose-enriched syrup (HFES), a sweetener (a liquid sugar), can be made from taro starch. Also taro can be a source of alcohol. The estimated alcohol yield from taro was estimated at 142 L/MT with a crop cycle of 9–15 months. Roughly, the starch-to-alcohol conversion ratio has been accepted to be 1.76 kg of starch to 1 L of alcohol.

Taro tops can be satisfactorily ensiled, and fermentation characteristics are comparable with other silages for animal feed. Taro silage can meet much of the feed needs for brood sows with no reproductive problems and good litter performance (Carpenter and Steinke 1983). Peelings and leaves and corms from wild types and inferior cultivars are fed to pigs. Boiled taro cormels were found to be comparable to maize as an energy source in the diets of weanling pigs (Agwunobi et al. 2002). Boiling significantly reduced the amounts of the antinutritional factors in the taro cormels. Samarasinghe and Rajaguru (1992) found that the feeding value of taro corms could be easily improved by boiling in water for 30–45 minutes and processed taro corm meal could be used to replace maize in broiler diets at

levels up to 100 g/kg without any adverse effects. Processed taro corm meal had gross energy 14.9–15.0 MJ/kg dry matter and was comparable with maize meal as an energy source.

Studies showed that *Colocasia esculenta* was one of the several wetland aquatic plants that could be used for phytoremediation of submerged soil polluted by arsenic (Jomjun et al. 2011). Taro was recognised as the largest and fastest arsenic remover in the study. Its arsenic removal rate was 68 mg As/m^2/day, while those rates of *Canna glauca*, *Cyperus papyrus* and *Typha angustifolia* were 61, 56, and 56 mg As/m^2/day, respectively.

Tarocystatin a group-2 phytocystatin was isolated from *Colocasia esculenta* and found to be a defence protein against phytopathogenic nematodes and fungi (Yang and Yeh 2005; Wang et al. 2008). The lectin *Colocasia esculenta* agglutinin (CEA) purified from taro corms significantly decreased the per cent pupation and emergence of *Bactrocera cucurbitae* with respect to control. CEA affected normal growth and development and presented stress to the larvae, activating their detoxification and antioxidant systems. Thus, the lectin may be a useful candidate for the control measures of *B. cucurbitae* under the integrated pest management (IPM) system. Taro corm agglutinin CEA was found to have insecticidal activity against *Bemisia tabaci* and *Lipaphis erysimi* (Roy et al. 2014). CEA interacted with insect midgut receptors that probably led to disruption of cellular processes causing growth retardation and loss of fecundity of target insects. Taro was found to be an effective trap crop for managing *Spodoptera litura* on tobacco; however, it did not attract *S. litura* in the seedling stage, indicating that taro should either be planted 20–30 days before tobacco or alternative control methods should be employed during the seedling stage (Zhou et al. 2010). The purified α-amylase inhibitor from *Colocasia* corm was found to inhibit activity against α-amylases extracted from the larvae of *Callosobruchus chinensis*, *Tribolium castaneum* and *Corcyra cephalonica* and midgut α-amylase of *Spodoptera littoralis* (Kumari et al. 2012). One hundred percent larval mortality of *C. cephalonica* was observed when fed on wheat flour mixed with 0.0036 % (w/w) of purified inhibitor. The ability of the inhibitor to inhibit insect amylases highlighted its possible role in pest resistance and postharvest decay of crop plants.

Studies found that taro can be used as a vermicompost for the growth and proliferation two epigeic species (*Eisenia foetida* and *Eudrilus eugeniae*) of earthworms (Kurien and Ramasamy 2006).

Kalo is also steeped in cultural and religious beliefs. Kalo was the *kinolau* (body form) of the Hawaiian gods Kane (the great life giver) and Lono (god of peace, planting and fertility) (Abbott 1992). As such, kalo was one of the foods offered to appease these two gods in particular.

Leaves and petioles of the taro plant were used to make dyes for *kappa.* Kalo is also used in landscaping or horticultural use where horticultural varieties are used primarily to incorporate in garden, lawn and exterior plant design, not necessarily for consumption. Fibre obtained from the leaf stalk has been used for plaiting in Africa.

Comments

Colocasia esculenta is a very variable species that is widely cultivated throughout tropics and many wild or naturalised clones found in S. Asia, Malesia and the Pacific islands. Its taxonomy had been controversial. Bailey (1925), Hill (1939) and Jonker-Verhoef and Jonker (1959) recognised *Colocasia esculenta* as one of the main species, while Barrau (1957) recognised them as two separate species *C. esculenta* and *C. antiquorum*. Haudricourt (1941) retained the name *C. antiquorum* for the main species and made a number of botanical varieties based on vegetative characters. Purseglove (1972) recognised two botanical varieties of cultivated C. *esculenta*, namely, var. *esculenta* and var. *antiquorum*. He suggested that the dasheen of the West Indies (which is generally referred to as taro in the Pacific) should be considered as *C. esculenta* var. *esculenta* and that the eddoe of the West Indies (generally referred to as dasheen in the Pacific and in Asia) is considered as *C. esculenta* var. *antiquorum*.

In *C. esculenta* var. *esculenta* (dasheen, taro type), stolons are absent, appendix is short, leaf lamina is adaxially matte waxy glaucous and water shedding, infructescence is not erect and the central corm is large, cylindrical, up to 35 cm long and 15 cm in diameter, with small side cormels. In *C. esculenta* var. *antiquorum* (eddoes type), stolons are present, appendix is elongated, leaf blade is adaxially glossy and wettable, infructescence is erect and the central corm is much smaller and bears many small secondary cormels.

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Cyrtosperma merkusii

Scientific Name

***Cyrtosperma merkusii* (Hasskarl) Schott**

Synonyms

Arisacontis chamissonis Schott, *Cyrtosperma bantamense* Koord., *Cyrtosperma chamissonis* (Schott) Merr., *Cyrtosperma cuspidilobum* Schott, *Cyrtosperma dubium* Schott, *Cyrtosperma edule* Schott ex Seem, *Cyrtosperma ferox* N.E.Br. & Linden, *Cyrtosperma intermedium* Schott, *Cyrtosperma lasioides* Griffith, *Cyrtosperma merkusii* (Hassk.) Schott, *Cyrtosperma merkusii* var. *giganteum* Nadeaud, *Cyrtosperma merkusii* var. *intermedium* (Schott) Engl., *Cyrtosperma nadeaudianum* J.W.Moore, *Lasia merkusii* Hasskarl.

Family

Araceae

Common/English Names

Gallan, Giant Swamp Taro, Swamp Taro

Vernacular Names

Caroline Islands: Fulah, Muen, Musaing An Ngatik, Onokokung, Ponon, Simetun, Sinaitah
Chinese: Qu Zi Yu
Chuuk: Bula, Fanan, Pashon, Pashok, Pila, Pwula, Simiden
Cook Islands: Paluku, Puraka
Fiji: Tao Kape, Via, Via Kana
French: Siguine, Taro Géant Des Marais, Taro Des Atolls
French Polynesia:'Apeveo, Taa Faa
Kilinailau (Carterets Island): Pulaka
Kiribati (Gilberts): Baba, Babai, Te Babai
Hawaii: Maota
Ifaluk: Pulax
Indonesia: Umbi Daluga
Kapingamarangi: Bulaga, Puraka
Kosrae: Pashon, Pashok, Pasruk
Lamotrek: Bulokh
Malaysia: Birah Hutan, Geli-Geli, Kaladi Pari
Marianas Islands: Baba
Marquesas Islands: Kape Taataa, Tdo-Kape-Taa-Taa
Marshall Islands: Buroro, Kailiklik, Laraj, Laratz, Larej, Wan
Namoluk: Pula
Nukuoro: Bulaga
Nukutapu (Tasman Island): Vakehu

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Onotoa: Te Babai
Palau: Brak
Papua New Guinea: Swamp Taro
Philippines: Galiang (Bikol), Palau (Cebu Bisaya), Palauan (Panay Bisaya), Palauan (Samar-Leyte Bisaya)
Pingelap: Muang, Muhang, Muiang, Mwang, Mwahng
Pohnpei: Muang, Muhang, Muiang, Mwang, Mwahng
Puluwat: Bula, Pwula
Polynesian: Ape Veo, Brak, Brokka Maota, Kape Taa Taa Lok, Peves, Pula'a Pulaka, Puna, Pura, Puraka, Pwolok, Simindou, Wasrmar, Tao, Ula
Ponape: Muiang, Mwong
Raiatea (Society Islands): Opevea
Samoa: Pula'a
Satawal: Pula
Solomon Islands: Kakae, Kakake, Karake, Kakama, Kanokano, Te Puraka, Vakehu, Pulaka
Spanish: Gallan
Tahitian: Ape De Veo, Kli, Maota
Tauu (Mortlock Islands): Kano Kano, Tepuraka
Tokelau: Pulaka
Tongan: Pula'a, Via
Tuvalu (Ellice Islands): Brokka Borkka, Pulaka
Ulithi: Bwolok, Bwolkh, Puns, Pura, Pwolok
Vanuatu: Navia
Vietnamese: Hạt Cong, Ráy Đuôi Dài
Western Polynesia: Pula'a, Pulaka, Puraka
Woleaisan: Bwolog
Yap: Lak, Lok

Origin/Distribution

Swamp taro is native to Malesia (probably Malaysia and Indonesia) and was introduced to and spread among western Melanesia and the Pacific islands in pre-European times. It is common in Malaysia, Singapore and Indonesia and rare in Papua New Guinea. Formerly a popular crop through Malaysia and Indonesia and a staple in the Philippines; today hardly any cultivation is seen there. An important food and staple crop in Micronesia but a minor food crop in Polynesia.

Agroecology

The plant grows in coastal swamps, swamp forests, riverbanks, in shallow water or brackish water. It grows on a wide range of soil types and acidity. It is also tolerant of saline and calcareous soils. In parts of Micronesia, it is grown in man-made, muck-filled, freshwater swamps and also on artificial elevations. It prefers natural swamp land rich in humus and covered with 0.2–0.7 m of slow running water. It can be cultivated in areas of moderate rainfall provided the soil is deep and swampy. It thrives in full sun or partial shade and should be sheltered from strong winds.

Edible Plant Parts and Uses

The large tuberous rootstocks are eaten after thorough cooking by boiling, steaming or roasting. The tubers can be peeled, sliced, fried and eaten with sugar. The tubers can be preserved by peeling, slicing, scalding and drying in the sun for future use. The tubers are also used to produce starch and flour. Young leaves and inflorescences are also eaten cooked as vegetables.

The starchy rhizomes are important staple in Micronesia. In Kiribati which comprises three groups of atoll islands – Gilbert group with 17 islands, Phoenix group with 8 and Line group with 8 – *C. merkusii* has been and is the biggest root crop grown for centuries. Swamp taro is second to coconut as source of vegetable food and is consumed for its high-valued starch. The tubers are often cooked with coconut milk in various cuisines. Some common Micronesian recipes with swamp taro (Manner 2011) are:

(a) Wūdeñ – with cooked and pounded breadfruit, swamp taro, bananas or nuts mixed with grated coconut
(b) Jebwater – food with grated swamp taro mixed with coconut milk, wrapped in taro leaves and baked in oven
(c) Totaimon – food with swamp taro grated and mixed with coconut oil and coconut sap
(d) Kōmālij – mashed swamp taro or potato
(e) Jukjuk – pounded swamp taro mixed with coconut

(f) Te buatora – grated babai corm mixed with sugar or kamaimai and cooked in boiling water or baked in oven by wrapping in leaves
(g) Te bekei te buatoro – babai mixed with coconut cream and more sugar
(h) Te korokoro – raw babai cut into small slices and boiled in water or baked in oven
(i) Te rebun – boiled or baked babai pieces added with coconut cream or kaimaimai
(j) Te tangananimanam – babai pieces already boiled or cooked are meshed together and mixed with grated coconut

Botany

Tall, robust, perennial herb reaching 3–5 m high, with typically six to eight huge leaves arising from a short stem (Plate 1). The stem thickens at the base becoming a large subterranean rhizome corm, varying in shape from cylindrical to conical. The size of corm varies with cultivar and age; 15–25 kg is common, but it can weigh up to 90 kg or more in a 10-year-old plant. Leaves are coriaceous, dark olive green, huge, 1–2 m long, erect, hastate–sagittate with long basal lobes and tapering apices, deep sinus, anterior lobe shorter than the posterior lobes and tip pointing upwards, with long stout, 2.5 m long petioles, covered with spines near the base, arising spirally from top of corm; venation is reticulate and prominent on undersurface (Plate 2). The inflorescence is a solitary spadix on a long peduncle (Plate 3). The spadix is enclosed by hard, marcescent spathe, purple coloured often with yellowish stripes, sometimes leaf-like and greenish white. The spadix is sessile or stipitate, yellowish, with hermaphrodite flowers throughout its length, with four to six free tepals. Fruits are small, globose, orange to scarlet berries ripening from the tip of the spadix downwards. Seeds are tiny, kidney to helical shaped, often ornamented.

Plate 1 Swamp taro plant in situ

Plate 2 Swamp taro leaves

Plate 3 Swamp taro inflorescence

Nutritive/Medicinal Properties

Food value of the raw giant swamp taro corm per 100 g edible portion was reported as water 75 g, energy 308 kcal (75 kJ), protein 0.5 g, total fat 0.2 g, available carbohydrates 18 g, dietary fibre 2.8 g, sodium 72 mg, potassium 67 mg, calcium 182 mg, magnesium 21 mg, iron 0.6 mg, zinc 2.1 mg, total vitamin A equivalent 5 μg, β-carotene equivalent 30 μg, thiamine 0.03 mg, riboflavin 0.02 mg, niacin traces, vitamin C 15.7 mg and vitamin E 2 mg (Dingan et al. 1994).

Studies reported that β-carotene concentrations of giant swamp taro cultivars varied from 50 to 4,486 μg/100 g (Englberger et al. 2008). Alpha-carotene content varied from 9 to 2,040 μg/100 g and β-cryptoxanthin from <10 to 120 μg/100 g. Australian analyses found in five cultivars lutein levels of 852–1,548 μg/100 g, while Swiss analyses of 24 cultivars found mean lutein level of 67 μg/100 g and maximum level was 260 μg/100 g. Zeaxanthin and lycopene occurred at low levels 10–20 μg/100 g or not detected in all samples. Yellow-fleshed cultivars generally contained higher carotenoid concentrations. Of the ten cultivars analysed for mineral content (wet weight basis) per 100 g, substantial concentrations of zinc 5.4–46.1 mg, iron 0.3–0.8 mg and calcium 121–305 mg were found, and other minerals were potassium 111–282 mg, magnesium 11–51 mg, manganese 1.7–5.1 mg, sodium 13–78 mg, phosphorus 21–24 mg were found. All cultivars were acceptable for taste and production factors. The researchers suggested that the carotenoid- and mineral-rich cultivars should be considered for promotion in Micronesia and other areas for potential health benefits.

Workers in the Philippines have reported a starch content ranging from as low as 7.5 % up to 22.6 %. The starch granules are of medium size, from 4 to 18 μm, and rounded or angular (Kay 1973).

Slices of the yellow and mixed sections of the tubers were processed into flours by sun-drying (temperature about 35 °C) and hot air electric drying at varying temperatures (50, 60, and 70 °C) before milling (Nguimbou et al. 2013). Drying temperature and technique exerted marginal effect on the protein, fat, fibre, ash and carbohydrate content of taro flours. Colour attributes, physical and functional properties, 1,1-diphenyl-2-picryl-hydrazyl radical antioxidant activity, as well as reducing power of flours were found to vary significantly due to either the drying temperature or method. Hot air electric drying at lower temperatures (<70 °C) produced flour with higher water absorption capacity (WAC), water solubility index (WSI), porosity, bulk density and preserved antioxidant activity of flour, whereas sun-drying was associated with flours of higher WSI but lower WAC and lower antioxidant capacity. It was noticed that carotenoids and ascorbic acid contributed to the antioxidant activity in swamp giant taro flours.

Traditional Medicinal Uses

The plant has limited medicinal use. According to Guerrero (1921), the spadix in decoction is used as an emmenagogue and ecbolic.

Other Uses

The plant is often grown as ornamental because of its large size (up to 4 m tall), and in certain parts of Micronesia it is a highly valued prestige plant.

Comments

The plant is commonly propagated from suckers (sprouting cormels), though the top of the corm of the harvested plant (setts) is also used.

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Xanthosoma sagittifolium

Scientific Name

***Xanthosoma sagittifolium* (L.) Schott**

Synonyms

Arum sagittaefolium hort. ex Steud., *Arum sagittifolium* L., *Arum sagittifolium* (Michx.) Pursh, *Arum xanthorrhizon* Jacq., *Caladium edule* G. Mey., *Caladium mafaffa* Engl., *Caladium sagittifolium* (L.) Vent., *Caladium sagittifolium* (Michx.) Nutt., *Caladium utile* Engl., *Caladium xanthorrhizon* (Jacq.) Willd., *Philodendron nigrum* Kunth (inval.), *Xanthosoma appendiculatum* Schott, *Xanthosoma atrovirens* K. Koch and C.D. Bouché, *Xanthosoma atrovirens* Fournet, *Xanthosoma atrovirens* var. *appendiculatum* (Schott) Engl., *Xanthosoma atrovirens* var. *hybridum* K. Koch, *Xanthosoma atrovirens* var. *kochii* Engl., *Xanthosoma atrovirens* var. *moritzii* Engl., *Xanthosoma atrovirens* var. *panduriforme* Engl., *Xanthosoma atrovirens* var. *versicolor* K. Koch, *Xanthosoma blandum* Schott, *Xanthosoma edule* (G. Mey.) Schott, *Xanthosoma ianthinum* K. Koch and C.D. Bouché, *Xanthosoma jacquinii* Schott, *Xanthosoma mafaffa* Schott, *Xanthosoma mafaffa* var. *blandum* (Schott) Engl., *Xanthosoma nigrum* Stellfeld, *Xanthosoma nigrum* Mansf., *Xanthosoma peregrinum* Griseb., *Xanthosoma poeppigii* var. *mafaffa* (Schott) J.F. Macbr., *Xanthosoma roseum* Schott, *Xanthosoma sagittifolium* K. Koch (illeg), *Xanthosoma utile* K. Koch and C.D. Bouché, *Xanthosoma violaceum* Schott, *Xanthosoma xantharrhizon* (Jacq.) K. Koch

Family

Araceae

Common/English Names

American Taro, Arrowleaf Elephant's Ear, Barbados Nut Eddoe, Cocoyam, Elephant Ears, Green Arrow Elephant Ears, Malanga, New Cocoyam, Tannia, Uyautia, Yannia Leaf Spinach (Leaves – Fiji), Yautia, Yautia Tannia, Yellow Yautia, Yellow Ocumo

Vernacular Names

Africa: Cocoyama, Macabo, Maduma, Malomba
Antilles: Choux-Caraibe, Malanga, Tannia Taniera
Argentina: Mairino, Uncucha, Yantia
Bangladesh: Dudh Kachu, Moulavi Kachu
Brazil: Adão, Cocó-Bravo Costela-De-Adão, Mangarás, Mangareto, Mangarito, Mirim, Taiá, Taioba, Taioba-Brava, Taiobuçu, Taioba-Mirim
Bolivia: Gualuza
Chinese: Yayu
Chuukese: Woten Sapan, Wotopwula

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Colombia: Bore, Mafafa, Malanga, Rascadeira
Cook Islands: Taro Taruā, Tarotaruā, Taruā (Maori)
Costa Rica: Pituca, Quiquisque, Tiquisque, Tiquisque Blanco
Cuba: Majaja, Malanga, Malanga Amarilla, Malanga Blanca, Malangay, Rascadera, Tania Ocumo, Taya, Wilis, Yautia
Danish: Tannia
Dutch: Tajer
English Antilles: Dashen
Estonian: Malanga Kollavõhk
Fijian: Dalo Ni Tana, Ghuya, Ndalo Ni Kana, Ndalo Ni Tana, Te Taorourou
French: Chou Caraïbe, Malanga Marron, Mangaride, Tannie, Tanier, Taye, Tayotte, Tayove, Yautia Des Anglo Saxons
French Antilles: Chinise Tayer, Huitina
French Guiana: Taye, Tayove
German: Goldnarbe, Okumo, Tannia, Yautia
Ghana: Amankani, Kotomle (Leaves) (Adangme), Amãkãni, Amankani Hiσ, Amankani Tchu, Amankanidzẽ (Adangme-Krobo), Amankani, Antwibo (Akan-Asante), Amankani, Mankani, Amankani Antwibo, Amankani Fita, Amankani Kokoo, Amankani Pa Amankani (Enti), Amankani (Ga), Amankani (Gbe-Vhe), Antwibo (Twi), Amankani, Nkontommere (Leaves) (Vulgar)
Guatemala: Quequesque
Guinea: G-Biné-Elin, G-Bune, Uayé (FB) (Kpelle), Gputé (Loma), Diabereen Puté, Gbéna-Uku (Manding-Maninka)
Guyana: Tannier, Tanyove
Hawaiian: Ape
Honduras: Quiscamote
I-Kiribati: Te Taororo
Indonesia: Kimpol
Japanese: To-No-Imo, Yautea
Malaysia: Keladi Betawi
Marshallese: Alōklōk, Kālōklōk
Mexico: Macal, Majaja, Malanga, Malangay, Queiquexque, Rascadera, Tania Ocumo, Taya, Wilis
Nauruan: De Taro
New Caledonia: Hebrdean Taro
Nigeria: Ìyòkhó Àkàrá Ìyòkhó Àkàrá (Edo), Àta Ḿkpọ̀ŋ Mbàkárá, Idídùòt ḿkpọ̀ŋ° Mbàkárá (Efik), Kúmaàtún Mùzuúruú (Huasa), Àkàsị̀ Óyìbó, Édè Árọ̀, Édẹ Bẹ̀kẹ̀è, Édè Ékò, Édẹ Ọ̃kpọ́rọ́, Ǹkàsí Bèkéè, Ukurukuru (Igbo), Bèké Òdú (Ijo-Izon), Édè Ọ́hẹ̀á (KW), Údū Òyìbó (Urhobo), Gwaàzaàmai-Goòraá, Gora, Kan-Birii (Zog)
Niuean: Pulaka
Palauan: Bisech Ra Ruk, Eball, Saibal
Panama: Otó
Papua New Guinea: Kongkong Taro
Peru: Uncucha
Pohnpeian: Sawahn Awai
Polynesia: Talo Njumea, Talo Palagi
Portuguese: Mangará Mirim, Magarás, Mangarito, Mangareto, Taioba
Puerto Rico: Yautía Amarilla, Yautía Blanca, Yautia Braviá
Rakahanga-Manihiki: Taro Taruā
Samoa: Talo Paplagi, Taro Palagi, Talo Njumea
Satawalese: Yigalulu
Senegal: Makabo, Malanga (Vulgar)
Sierra Leone: E-Lɛba, Koku-Lɛ (Bulom), Jabɛrɛ, Jabɛrɛ-Koko, Yabɛrɛ (Fula-Pulaar), Duu (Gola), Waye-Bɛnde, Wayele, Wayilẽ (Kissi), Koko (Kono), Koko (Krio), Kogo (Limba), Koko (Loko), Yabɛre (Manding-Mandinka), Koko (Mende), Koko (Susu), Yagbɛri-Na (Susu-Dyalonke), Am-Bɛroŋ, An-Yabɛrɛ, An-Gbaŋkaŋ, An-Koko, An-Kol (Temne), K-Posi (Vai)
Solomon Islands: Taro Kong Kong
Spanish: Mangaras, Mangarito, Malanga Amarilla, Mafafa, Ocumo, Otoy, Tanier, Tiquisque Blanco, Tiquisqui Calus, Yautía Blanca, Yautía Brava
Sri Lanka: Alakala, Dehiala, Desai-Ada, Gahala, Kaparala, Kiriala, Kokis-Ala, Rata-Ala, Ratu-Habarala, Sevel-Ala, Sudu-Kaudala, Tummas-Ala, Yakutala, Yokkala
Tahitian: Taroua, Tarua
Taiwan: Qian Nian Yu
Togo: Mankani (Gbe-Vhe)
Tonga: Talo Futuna
Truk: Yautia
Tuvaluan: Talo Palagi
West Cameroons: Makao (Bafok), Dìkàbò (Duala), Mbanga (Koosi), Nda (Kpe), Bende (Kundu), Makabo (Long), Mesengu (Lundu), Nda-Mukala (Mbonge), Bamboko (Tanga), Makara, Mankamo (Vulgar), Nda (Wovea)
West Indies: Tayo Tyo

Vanuatu: Taro Fiji
Venezuela: Malanga Malangay, Ocumo, Ocumo Cuman Taro

Origin/Distribution

This tropical species is believed to have originated from northern South America and spread to the Caribbean and Mesoamerica and subsequently introduced elsewhere into Africa, Asia and the Pacific.

Agroecology

The species is adapted to the wet, humid and warm tropics. It requires moist but well-drained, fertile soil and prefers partial shade. The mean temperature for their optimum growth must exceed 20 °C. In its natural habitat, it grows commonly under the rainforest canopy or naturalised along shady stream banks, but does not grow under flooded or swampy conditions. Although of tropical origins, the plant can withstand short periods of low cold temperature.

Studies by Caesar (1980) found that Barbados nut eddoe (*Xanthosoma sagittifolium*) produced the highest dry matter yield under shade and full water supply by developing long petioles and large leaf blades. Under shade and water stress, only the corm grew, and the growth of cormels was negligible. As a result of the increased development of above-ground plant organs, the plant was able to survive stress conditions but with a low yield of edible organ material.

Edible Plant Parts and Uses

This tropical plant is an important food crop – its edible corms provide energy-rich carbohydrates. They are eaten in various ways: boiled, steamed, baked, grilled, fried, mashed, creamed, pureed, in soups, chowders, stews and salads or barbecued whole (Kay 1987; Jansen and Premchand 1996). The corms are also dried, peeled and ground to flour or meal for pastry that can be stuffed with meat or other fillings or to prepare puddings.

Cocoyam was found to be superior to barley or sorghum for brewing beer due to it higher carbohydrate content (71–78 %) (Onwuka and Eneh 1996). The kiln-dried *X. sagittifolium* afforded a dark lager beer (4.16 % w/v alcohol content) with good aroma (68 %) and very good flavour (73 %) when compared with a commercial lager beer (Monarch) as standard (100 %).

The young leaves are valued as boiled vegetable.

Botany

A robust herbaceous, unarmed, lactiferous perennial (Plates 1 and 2), reaching 1.5–2 m high with a corm or main subterranean stem in the form of rhizome with the main part short, thick, globose or cylindrical giving rise to lateral off-shoots

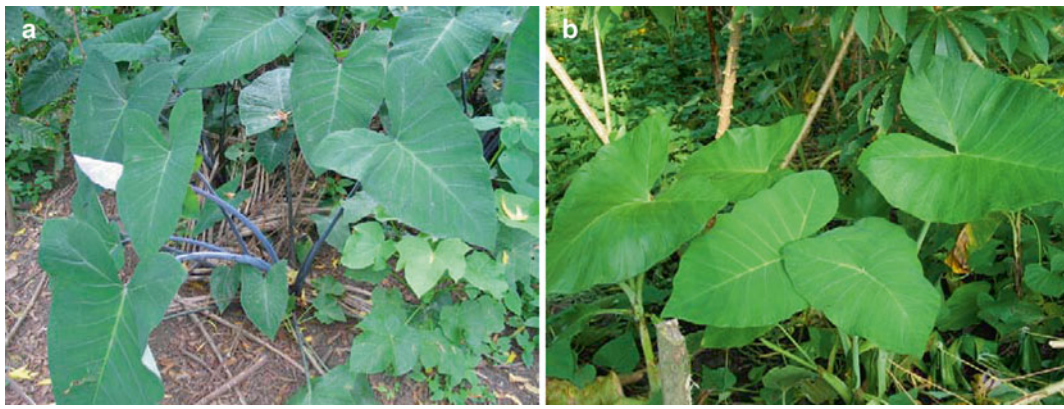

Plate 1 Tannia plant (**a**) *purple* 1 petioled, (**b**) *green* petioled

Plate 2 Tania leaves

(cormels) (Plates 3, 4 and 5). Corm pale brown and flesh white, pale yellow or pink. Several large leaves also sprout from the main part. Leaves are thick, dark green or purplish, long petioled (petioles up to 1.5 m long), sagittate or hastate not peltate lamina, up to 90 cm long and up to 60 cm wide, acute apices and wide basal lobes with prominent marginal nerves or pedatisect (Plates 1 and 2). Spathe with an ovoid or oblong convolute tube and a narrow boat-shaped blade exceeding the spadix. The large spathe is light green, silver green, yellow green or purple. The large cylindrical spadix, 15–20 cm long, is divided into female (lower) and male (upper) parts separated by a sterile zone. Staminate

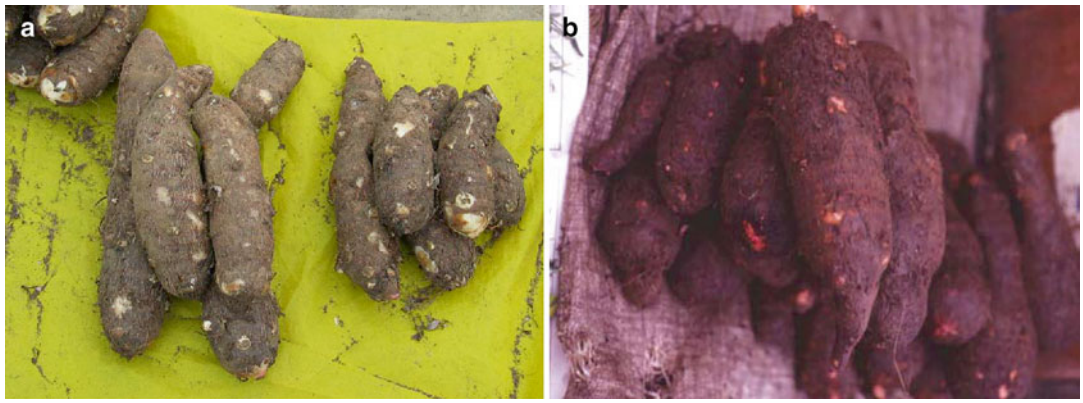

Plate 3 (**a**) *White*-fleshed corms, (**b**) *pink*-fleshed corms

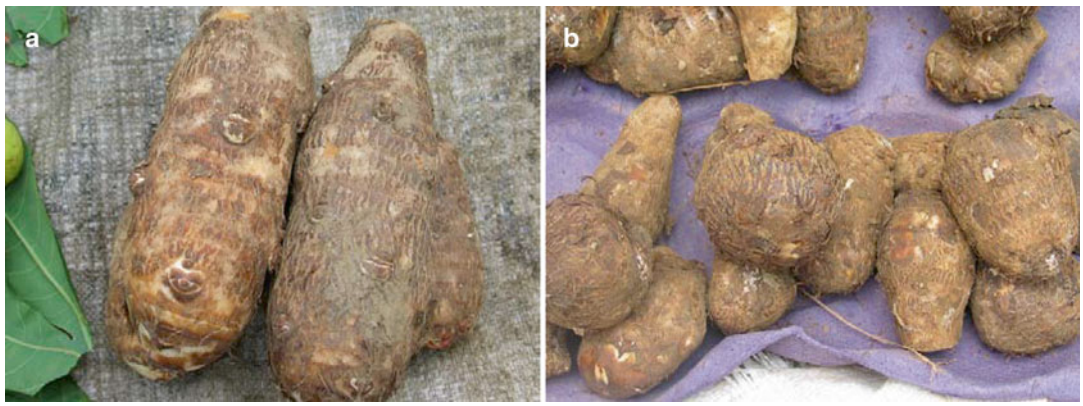

Plate 4 (**a**, **b**) Tannia corms and cormels (Papua New Guinea)

Plate 5 Tannia cormels (Fiji)

flowers of four to six stamens united in synandria; pistillate flowers with broad and coherent styles, disc-like stigma and the ovaries 2–4-locular with many subanatropous ovules borne near the centre of the axillary placenta. Berry polyspermous with few ovoid sulcate seeds.

Nutritive/Medicinal Properties

Corm/Corm Nutrient/Phytochemicals

The proximate nutrient food value of raw cocoyam corm based on analyses conducted in Nigeria is reported as per 100 g edible portion: Na 66 mg, K 525 mg, Mg 46.6 mg, C 18.64 mg, Fe 0.42 mg, P 70.4 mgm Zn 0.4 g mg and Mn 0.63 mg. Both white- and red-fleshed corms provide good sources of Na, K, Mg and Ca.

Approximate composition of tannia per 100 g edible portion was reported by Kay (1987) as energy 556 kJ/100 g, moisture 70–77 %, protein 1.3–3.7 %, fat 0.2–0.4 %, carbohydrate 17–26 %, fibre 0.6–1.9 %, starch 17–34.5 %, ash 0.6–1.3 %, Ca 20 mg, Fe 1 mg, thiamine 1.1 mg, riboflavin 0.03 mg, niacin 0.0005 mg and ascorbic acid 6–10 mg. Tannia was reported to have larger starch grains (mean diameter of 17–20 μm) that were less easily digested than *Colocasia esculenta* (taro) starch grains. However, tannia starch was reported as palatable as cassava flour and more nutritious. Noodles made from mixes of soy, wheat and tannia flours had been made experimentally (Kay 1987).

The mean values of the proximate composition of *X. sagittifolium* (red flesh), *X. sagittifolium* (white flesh) and *Colocasia esculenta* corms per 100 g edible portion DM were reported, respectively, as moisture 57.63–77.41 g, 54.46–71.97 g and 59.30–72.06 g; protein 3.94–4.09 g, 4.92–5.50 g and 2.98–4.69 g; starch 12.3–33.61 g, 18.03–36.64 g and 17.81–32.53 g; fat 0.43–0.74 g, 0.28–0.58 g and 0.64–0.97 g; ash 2.68–3.93 g, 1.98–3.29 g and 1.56–1.88 g; fibre 1.16–1.77 g, 1.11–1.72 g and 2.74–3.00 g; Ca 7.70–24.33 mg, 7.91–18.99 mg and 4.68–7.09 mg; Fe 2.62–3.73 mg, 3.34–3.89 mg and 2.68–3.75 mg; Mg 64.48–85.03, 58.86–67.57 and 48.71–64.78 mg; Zn 20.87–51.05 mg, 28.33–51.09 mg and 16.98–28.41 mg; K 769.61–1525.80 mg, 963.05–1388.68 mg and 763.98–1004.63 mg; Na 21.07–23.70 mg, 28.91–49.14 mg and 28.48–34.622 mg; P 47.71–63.07 mg, 41.58–52.51 mg and 54.72–61.25 mg; and oxalate 253.49–380.55 μg, 269.49–322.82 μg and 328.41–488.9 μg (Afoakwa et al. 2003). The *Xanthosoma* (white flesh) variety had the highest levels of nutritive value. Similarly, the distal sections of the three yams studied had comparatively higher amounts proximate composition than the middle and apical sections. High levels of minerals were located at the apical sections as compared to the distal and middle sections. The apical section of all the species had high-protein content, while the distal section had high levels of ash, fibre and minerals. Potassium, zinc, magnesium and phosphorus were the most abundant minerals. Oxalate contents were lower in *X. sagittifolium* and higher in *C. esculenta*. The various processing methods used reduced the oxalate levels by approximately 50 % (Afoakwa et al.). The greatest reduction was observed for the drum-dried products. No significant differences were found between the oven-dried and solar-dried samples. The results implied that solar-, oven- and drum-drying techniques which reduced the oxalate contents to safer levels could be used for the development of marketable dehydrated products.

Xanthosoma sagittifolium (white flesh) was composed of Na (1365.05), K (3057.16), Mg (313.70), Ca (190.93), Fe (8.28), P (44.39), Zn (2.49) and Cu (0.52) (mg/100 g) and *X. sagittifolium* (red flesh) was found to contain Na (1297.89), K (1737.48), Mg (314.30), Ca (107.38), Fe (9.11), P (44.94), Zn (3.10) and Cu (0.78) (mg/100 g) (Njoku and Ohia 2007).

The mean values of the proximate composition of *X. sagittifolium* (white flesh), *X. sagittifolium* (red flesh) and *Colocasia esculenta* cormels evaluated were crude protein 2.98–5.50 g/100 g, total fat 0.28–0.97 g/100 g, ash 1.56–2.98 g/100 g, starch 12.2–36.0 g/100 g and crude fibre 1.11–3.00 g/100 g (Sefa-Dedeh and Kofi-Agyir 2004). The different sections of the cocoyam cormels studied were significantly different in chemical composition. The apical section of all the species had high-protein content, while the distal section had high levels of ash, fibre and minerals. Potassium was the most abundant mineral (763–1,451 µg/100 g) with appreciable amounts noted for zinc (17–51.1 µg/100 g), magnesium (46.7–85.0 µg/100 g) and phosphorus (41.6–63.1 µg/100 g). Oxalate compositions of the fresh samples were in the range of 254–381 µg/100 g for the *X. sagittifolium* (red flesh), 302–323 µg/100 g for the *X. sagittifolium* (white flesh) and 328–460 µg/100 g for the *Colocasia esculenta.* No significant differences were found between the oven-dried and solar-dried samples. However, drum drying reduced the oxalate levels by approximately 50 % to average levels ranging from 99.9 to 191 µg/100 g.

Protein, fat, ash and fibre contents of the raw cocoyam (% dry weight) were 2.83, 0.93, 1.74 and 0.88 respectively (Akpan and Umoh 2004). The protein, fat, ash and fibre contents decreased to 1.48, 0.72, 1.70 and 0.76 in the sample cooked without tetracycline (C_2). Significant decreases were observed when cocoyam samples C_3–C_6 were cooked with 1 g (1,000 mg) of tetracycline as the values decreased to 1.13, 0.48, 1.33 and 0.57 (% dry wt), respectively. Mineral elements analysis showed general decreases in the cooked samples. There was a 17 % reduction in calcium between C_1 and C_6, and similar trend was observed for other mineral elements**.** A general reduction in the level of antinutrients was observed after heat and tetracycline treatments. There was an improvement in food quality with respect to the antinutrients but with decreased values of the desired nutrients. However, there was also a general reduction in the undesirable properties of the cocoyam such as the acridity factors caused by crystal of oxalate when the corms of cocoyam were cooked with and without tetracycline. Studies showed that boiling (90 °C) affected the highest oxalate reduction in *Colocasia esculenta* cultivars and *Xanthosoma sagittifolium* corm flours, especially in the former (Iwuoha and Kalu 1995). Boiling and roasting (165 °C) affected reduction in cold paste viscosity, while an inconsistent trend resulted from steeping (30 °C). Gelatinisation temperature decreased, and water and oil absorption capacities increased markedly due to the three processes. Process time variation in steeping and boiling of *C. esculenta* on both water and oil absorption was significant. On the other hand, only the effect of cultivar on viscosity of both steeped and boiled samples was significant.

Starch granules sizes in the ranges of 0.74–1.19 and 0.74–1.10 µm were obtained for the *X. sagittifolium* (red flesh) and (white flesh), respectively (Sefa-Dedeh and Kofi-Agyir 2002). Significantly, smaller sizes (0.05–0.08 µm) of starch granules were observed for *Colocasia esculenta. C. esculenta* showed lower hot paste viscosity but higher thermal stability than the *Xanthosoma* varieties. Peak viscosity was highest in the *X. sagittifolium* (red flesh) variety, while the white-flesh variety showed the least tendency to retrogradation. Significant differences in raphide sizes were observed among the varieties, with the *C. esculenta* having more pronounced needle-like structures.

Ash content, fat content, crude fibre, protein and amylose contents of new cocoyam starch were reduced following modifications by oxidation (oNCS), acetylation (aNCS) and acid-thinning (atNCS) (Lawal 2004). The starch granules were round and polygonal in shape, the sizes ranged from 15 to 40 µm and the granule morphology was not altered by the modifications. The X-ray pattern of native starch was A

type, with similar pattern in modified derivatives. Acetylation improved swelling capacity, while oxidation and acid-thinning reduced it. Both oxidation and acid-thinning markedly improved solubility, whereas acetylation reduced it. Hydrophilic tendency of the starch improved after oxidation and acetylation, whereas acid-thinning reduced it. Oil absorption capacity increased after oxidation and acetylation but was reduced following acid-thinning. Oxidation and acetylation reduced the gelation capacity of native starch, while atNCS had better gelating property than nNCS. The pasting temperature of nNCS (76 °C) was reduced after oxidation and acetylation but increased following acid-thinning. Setback tendency of the native starch was reduced after oxidation and acetylation but increased following acid-thinning. Oxidation and acetylation reduced peak temperature of gelatinisation (T_p) of native starch, opposite to the increase in T_p after acid-thinning. Enthalpy of gelatinisation (ΔH) was reduced after oxidation and acetylation but increased following acid-thinning. Retrogradation tendency was reduced after oxidation and acetylation but increased following acid-thinning. Hydrothermal modification of native *X. sagittifolium* did not alter granule morphology; starch granules were round and polygonal shapes with sizes ranging from 15 to 40 μm and with 'A' X-ray diffraction pattern (Lawal 2005). Swelling power and solubility were reduced following hydrothermal modifications. At all pH studied (2–12), native new cocoyam starch exhibited higher swelling capacity and solubility than the modified derivatives. Hydrothermal modifications improved water absorption capacity but reduced oil absorption capacity. Pasting temperature of native starch shifted to higher values following annealing and heat moisture treatment. Hot paste viscosity (Hv), viscosity after 30 minutes holding at 95 °C (Hv30) and cold paste viscosity (Cv) reduced after annealing and heat moisture treatment. The result also indicated that hydrothermal treatments reduced the tendency for setback. Following annealing and heat moisture treatment, gelatinisation temperature increased. Starch hydrothermal modifications reduced retrogradation as enthalpies of regelatinisation reduced following modifications.

Studies showed that the amylose content of the starch isolated from *Xanthosoma sagittifolium* was higher than those shown by *Colocasia esculenta* and *Manihot esculenta* starches (Pérez et al. 2005). The phosphorous content was higher in *Xanthosoma sagittifolium* than *Colocasia esculenta* or the commercial *Manihot esculenta* C. starches. The gelatinisation profile range was wider in *Manihot esculenta C.* than the other two starches. The most significant relationship between parameters was found between the amylose and gelatinisation profile and enthalpic change and ash. *C. esculenta* flour showed higher crude fat, total, soluble and insoluble dietary fibre and mineral (P, Ca, Fe and Zn) contents, whereas *X. sagittifolium* flour showed higher starch and ash and reducing sugar content (Pérez et al. 2007). *X. sagittifolium* flour showed higher titratable acidity and relative density values, being darker and more yellowish than its counterpart. *X. sagittifolium* flour showed higher gelatinisation temperature than *C. esculenta* flour. Parameters such as viscosity during the holding time (95 °C for 30 minutes), viscosity at 50 °C, setback and consistency were lower in C. *esculenta* flour than *X. sagittifolium* flour. The viscosity peak and breakdown indices were higher in *C. esculenta* flour than in the *X. sagittifolium*.

Cocoyam corms planted in the summer showed higher contents of total starch than corms planted in other seasons (Lu et al. 2005). Starches from both cultivars (KCX01 and KCX02) of cocoyam corms planted in the summer season had significantly higher average granule sizes, higher contents of amylose, higher ratios of short-to-long chains of amylopectin and lower values of the average degree of polymerisation (DP) of the chain length distribution profiles. The distinct properties of the fine structure of cocoyam starch from corms planted in summer season were associated with lower values of onset and peak temperatures and enthalpies of gelatinisation. *Xanthosoma sagittifolium* and *Colocasia esculenta* starches were white in colour and had granule sizes varying significantly in length

(6.47–13.63 μm) and width (5.36–8.45 μm), while amylose content ranged from 11.55 to 33.77 % (Falade and Okafor 2013). Peak (49.09–141.96 RVU) (rapid visco units), breakdown (49.09–141.96 RVU), final (189.79–327.42 RVU) viscosities, pasting temperature (84.53–88.75 °C) and time (4.55–4.97 minutes) varied significantly among cultivars. Also, water absorption capacity (21–36 %), pH (4.8–5.3), gelling point (60.5–69.5 °C), foam capacity (4.46–18.28 %), bulk density (0.14–1.15 g/mL) and swelling power (2.31–10.09) varied significantly among the cultivars. The average yield of the starches varied significantly from 10.03 to 18.61 %.

Cocoyam peels were found to contain 6.30–17.6 % protein, 10.7–19.7 % fibre, 41.2–46.0 % carbohydrate and 0.70–2.14 % lipids (Yahaya et al. 2013). Macrominerals (Na, K, Ca and P) being the highest while the micromineral nutrients such as Mg, Zn, Fe and Cu were found to be generally lower than the dietary mineral requirement for animal feeds. The peels collected during dry season contained lower concentration of phytate which ranged between (1.26–1.43 %), hydrogen cyanide (3.17–3.20 %), soluble oxalate (1.18–1.69 %) and tannin (1.43–8.24 %) than the peels collected during wet season. The proximate analysis of the peels suggested that they could serve as supplementary sources of essential nutrients for livestock production, especially with their low levels of antinutritional factors.

The polygalacturonase inhibitory action, phenol oxidase and peroxidase activities were higher in cocoyam corms of the *X. sagittifolium* varieties infected by *Sclerotium rolfsii* than in those of the *Colocasia esculenta* varieties (Ohazurike and Arinze 1996). The levels of phenol oxidase, peroxidase and polygalacturonase inhibitory activities also decreased as the postharvest age of the corms increased.

Trypsin inhibitors with molecular weights 19,950, 17,780 and 23,390 isolated and purified cocoyam corms (Obidairo and Ofuru 1982). They showed varied trypsin inhibitory activity which was lost on boiling for 40 minutes and exhibited maximum activity at pH 7.5–8.0.

Uhegbu (1997) found that cocoyam (*X. sagittifolium*) contained diethylamine, dimethylamine, morpholine, ethylaniline and proline (ranging between 0.80 and 0.91 μg N/kg).

Leaf Phytochemicals

X. sagittifolium petioles were found to contain raphides, needlelike crystals about 50 μm long and with maximum dimensions of approximately 850 by 250 nm (Sakai et al. 1972). The raphides had two distinct end structures: narrow, acute and tapered to a point at one end and broad, acute and abruptly pointed on the other. Barbs, about 750 Å long with tips oriented away from the narrow end, occurred along the length of the raphide on ridges on either side of two longitudinal grooves. These grooves, located opposite each other, gave the raphide cross section an H-shape. Mean dry matter (DM) content of new cocoyam leaves was 9.7 %, crude protein was 29.7 % DM, ash 11.9 %, neutral detergent fibre 31.5 % and acid detergent fibre 11.9 %, while total oxalates content was 2.79 g/100 g DM (Lumu and Katongole 2011). Wilting of chopped leaves after 3 hours affected the lowest reduction (21.1 %) in total oxalate content. Boiling (52.1 %), ensiling (43.7 %) and soaking (41.8 %) were equally effective (there was no significant difference) in reducing total oxalate content.

Six tropical leafy vegetables (*Vernonia amygdalina*, *Pterocarpus soyauxii*, *Manihot utilissima*, *Xanthosoma sagittifolium*, *Colocasia esculenta* and *Amaranthus hybridus*) were found to be 10.3–34.4 mg ascorbic acid 100 g fresh weight (Oteng-Gyang and Mbachu 1987). Cooking led to significant losses (60–90 % after 15 minutes). During market sale, when the leaves remained exposed in the sun for several hours, losses as high as 97 % of the remaining ascorbic acid were recorded. Some of the vitamins were leached into the water which was not sold to the consumer, but discarded. Studies found that cocoyam (*Xanthosoma sagittifolium)* and white yam *Dioscorea alata* with GI (glycaemic index) 60 and 62, respectively, were considered as intermediate GI (glycaemic index) food in comparison to dasheen (77) and cassava (99), the high

GI food (Ramdath et al. 2004). The moderate GI of X. *sagittifolium* was also separately confirmed by Lako et al. (2004).

Antioxidant Activity

Animal studies showed that the ingestion of purslane or malanga leaves may have a protective effect against oxidative stress caused by vitamin A deficiency (Arruda et al. 2004). Rats fed with β-carotene, malanga and purslane leaves showed lower liver and heart thiobarbituric acid-reactive substances (TBARS) concentrations, lower liver GSH (reduced glutathione) concentration and lower heart GSSG (oxidised glutathione) concentration compared with vitamin A-deficient rats. Liver and heart catalase activities were not significantly different among the groups, nor was the heart glutathione peroxidase (GPX) activity; however, the β-carotene rats showed the highest liver GPX activity. In further studies, they reported that liver and heart lipid peroxidation was lower in rats fed with β-carotene and malanga carotenoids extract than the vitamin A-deficient rats, while no difference was observed for the malanga leaf powder group (Arruda et al. 2005). All three groups showed lower liver protein oxidation than the vitamin A-deficient group, and only the malanga carotenoids extract group had lower heart protein oxidation in relation to vitamin A-deficient group. The malanga leaf powder group had a lower liver GSSG concentration and higher GSH/GSSG ratio than the vitamin A-deficient group, while no difference was observed for heart glutathione concentration among the groups. The results indicated that at physiological levels, β-carotene, malanga carotenoids extract and malanga leaf powder had antioxidant effects in rats.

Xanthosoma sagittifolium corm contained 0.32 g 100 g-1 total phenolic; 0.26 g 100 g-1 flavonoid and exhibited good scavenging activity of DPPH (78.22 %), hydroxyl radical (69.11 %), superoxide radical (83.27 %) and ABTS radical cations (76.11 %). The study confirmed that the methanol extracts had potential in-vitro antioxidant activity (Nishanthini and Mohan 2012).

Anticancer Activity

Studies showed that healthy Wistar rats fed with lyophilised *X. sagittifolium* leaves for 4 weeks had increased faecal mass and fat excretion and improved bile acid profiles by diminishing the proportion of secondary acids, thus suggesting that consumption of taioba leaf may have the property of lowering the risk of colon cancer (de Almeida et al. 2013b). The leaves contained high contents of total fibre, predominantly comprising insoluble dietary fibre with glucose as the major monomer.

Hypolipidaemic Activity

The addition of lyophilised new cocoyam leaves to Wistar rats' diet resulted in reduced weight gain, reduced liver fat and increased faecal mass and lipid, in addition to higher faecal short-chain fatty acid and bile salt concentrations, compared to rats fed with a high-fat diet containing 3.67 % (w/w) cellulose (LCEL) for 4 weeks (de Almeida et al. 2013a). Additionally, only the group fed with a high-fat diet supplemented with 28.4 % cocoyam leaves exhibited a lower serum cholesterol concentration and a higher body ash content than the LCEL group. Both the high bile salt-binding capacity and high fermentability of lyophilised new cocoyam leaves suggested that *X. sagittifolium* may have a protective effect against cardiovascular diseases and bowel cancer.

Antidiabetic Activity

Administration of the ethanol extract of *Xanthosoma sagittifolium* corm at a dose of 200 mg/kg and 500 mg/kg body weight to alloxan-induced diabetic rats for 14 days elicited significant reductions of alloxan-induced-elevated blood glucose, serum creatine, urea, protein, albumin, globulin, glycosylated haemoglobin and hepatic enzymes serum glutamate pyruvate transaminase (SGPT), serum glutamate oxaloacetate transaminase (SGOT) and alkaline phosphatase (ALP)

back to normal levels (Shajeela et al. 2013). The extract also caused significant increase in plasma insulin in the alloxan diabetic rats. The extract also reverted the alloxan-elevated lipid profile parameters: total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), very-low-density lipoprotein cholesterol (VLDL-C) and phospholipids back to normal levels and significantly increased high-density lipoprotein cholesterol level. The highly significant reduction of activity of mitochondrial enzymes, reduced glutathione (GSH), oxidised glutathione (GSSG), GSH/GSSG, glutathione reductase (GR), glutathione peroxidase (GPx) and glutathione S-transferase (GST), and lipid peroxidation observed in alloxan-induced rats was reverted to normal values by *X. sagittifolium* ethanol extract.

Antiosteoporotic Activity

Fresh and cooked leaves of *X. sagittifolium* were found to have a low calcium content at 273.17 and 369.81 mg/100 g, respectively (de Oliveira et al. 2012). *X. sagittifolium* and *Laportea aestuans* represented two medicinal plant species used as food and to prevent and treat bone diseases, such as osteoporosis, in traditional Brazilian medicine. They showed that each species may be used as a health supplement in poor communities.

Antimicrobial Activity

Among 16 plants species tested, the best antifungal activity in-vitro against *Candida albicans*, *Trichophyton rubrum* and *Cryptococcus neoformans* was shown by *Xanthosoma sagittifolium* supernatant (Schmourlo et al. 2005). The most susceptible fungus was *Trichophyton rubrum.*

Vitamin A Replenishment Activity

Graebner et al. (2004) fed vitamin A-depleted rats with a basal diet (AIN-93G) in which the synthetic vitamin A content was replaced by nonconventional leaves. At the end of the 30-day repletion period, 1 μg of retinol was accumulated in the liver after the intake of 43.1, 95.3 or 178.9 μg β-carotene from *Sonchus oleraceus* (So), *Amaranthus viridis* (Av) and *Xanthosoma sagittifolium* (Xs) leaves, respectively. The relative bioavailability of β-carotene from the leaves was 36 %, 16 % and 9 % for So, Av and Xs leaves, respectively. The results showed that the carotenoids from the three dark-green leaves were absorbed, converted to retinol and stored in the liver of rats.

Traditional Medicinal Uses

In Peninsular Malaysia, the large leaves are used as blanket for patients with fever as they are pleasantly cool and provide temporary relief (Burkill 1966). Patients also bathe in the plant decoction. In Palawan, Philippines, the inflorescence sap is used to heal wounds and as an antidote for insect bites and stings. In northwest Amazonia, the Ketchwas people used a *Xanthosoma* sp. to treat snake bites (Schultes and Raffauf 1990).

Other Uses

All parts of the plant can be fed cooked to animals, particularly pigs. Cattle, sheep and goats like the leaves, which are unusually nutritious for leaves of a root crop and compare favourably with good pasture.

The results of feeding studies indicated the potential of fresh new cocoyam leaves to replace up to half the soybean protein in diets based on sugar cane juice for growing pigs (Rodriguez et al. 2006). Rodríguez and Preston (2009) found that mixed leaves and petioles of new cocoyam, in the proportions that occur naturally in the plant, can be ensiled successfully without the need for additives and ensure a permanent supply of silage for the pigs. Acceptability by pigs, ducks and hens was found to be excellent. Growing pigs (23 kg live weight) were able to consume diets containing up to 80 % of the DM

(dry matter) as ensiled new cocoyam leaves at levels close to 40 g DM/kg live weight (Rodriguez et al. 2009). Maximum N retention was achieved with the ensiled new cocoyam leaves providing 65 % of the diet DM, providing a protein level of 130 g/kg diet DM and 5 g crude protein per kg live weight. Studies showed that boiled cocoyam meals could effectively replace maize at 50 % inclusion level in finishing diets of broiler chickens (Abdulrashid and Agwunob 2012).

Comments

Most cocoyam varieties taste acrid and can cause the sharp irritation and burning sensation of the lips, mouth and throat when cocoyam leaves or corms are eaten raw (Bradbury and Nixon 1998). This acridity is caused by needlelike calcium oxalate crystals (raphides) that can penetrate soft skin and an irritant present on the raphides, probably a protease can cause discomfort in the tissue. Removal of the thick layer of skin and long period of cooking are required to remove acridity. Other methods of removal of acridity include fermentation, baking or extraction with ethanol.

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Panax ginseng

Scientific Name

***Panax ginseng* C.A. Meyer**

Synonyms

Aralia ginseng (C.A. Meyer) Baill., *Aralia quinquefolia var. ginseng* (*C.A. Meyer*) *auct*., *Panax schinseng* Nees, *Panax quinquefolius* var. *ginseng* (C.A. Meyer) Regel & Maack ex Regel, *Panax schinseng* var. *coraiensis* T. Nees, *Panax verus* Oken

Family

Araliaceae

Common/English Names

Asian Ginseng, Asiatic Ginseng, Chinese Ginseng, Five Fingers, Ginseng, Korean Ginseng, Korian Ginseng, Manchurian Ginseng, Oriental Ginseng, Red Ginseng (Steamed and Dried Peeled Roots), Tartar root, White Ginseng (Sun-Dried Roots)

Vernacular Names

Brazil: Ginsão, Ginseng Da China, Ginseng Da Coreia Do Sul, Jinsão (Portuguese)
Chinese: Jen-Shen, Ren-Shen, Ts'ao Shen, Yang Shen, Yuan Shen
Czech: Všehoj ženšenový, Ženšen pravý
Danish: Ægte Ginseng, Ginseng, Koreansk ginseng, Kraftrod, Orientalsk ginseng
Dutch: Echte ginseng, Ginseng, Koreaanse, Vingerplant
Estonian: Harilik ženšenn, Ženšen
Finnish: Ginseng, Ginsengjuuri
French: Ginseng, Ginseng asiatique, Ginseng coréen, Racine de ginseng
German: Asiatischer Ginseng, Chinesischer Ginseng, Gin-Seng, Ginseng-Wurzel, Koreanischer Ginseng, Kraftwurz, Kraftwurzel
Hungarian: ginszeng, koreai ginszeng, Kínai ginseng, kinai koreai ginseng
Italian: Ginseng
Japanese: Chousen Ninjin, Ninjin, Otane Ninjin, Yakuyou Ninjin
Korean: In-Sam, San Sam
Norwegian: Asiatisk ginseng, Ekte ginseng Ginseng, Kinesisk ginseng, Koreansk ginseng
Polish: Żeń-szeń, Zen-, Żeń-szeń prawdziwy

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Portuguese: Jinsão Da China
Russian: Zhen'shen', Zhen'shen' Obyknovennyi
Spanish: Ginseng, Ginseng Asiático, Ginseng Chino, Ginseng Coreano, Ginseng Rojo
Swedish: Ginseng
Thai: Som, Som Kao Li

Origin/Distribution

P. ginseng is indigenous to the mountainous forests of the northern temperate zone of Eastern Asia – Manchuria, northeastern China and Korea. It is widely cultivated in China, Korea and Japan.

Agroecology

Ginseng is a cool-temperate species, growing in partial or full shade of deciduous, moist forest. Wild population is scarce and the plant is mainly cultivated commercially in China and Korea. Commercially produced ginseng is either grown as undergrowth in shady forests or shaded by mats in the open in well-drained, moist, fertile soil.

Edible Plant Parts and Uses

The sliced roots of Chinese ginseng are eaten raw (in small quantities) and in salads or cooked with chicken in broth, porridge and soups. In Korea, a very popular and highly relished traditional chicken ginseng soup dish called *Samgyetang* is served in specialty restaurants all over Korea. The recipe comprises a whole young chicken stuffed with glutinous rice boiled in broth of Korean ginseng, dried Chinese jujubes, garlic and ginger. *Samgyetang* is traditionally served as a tonic in the summer for its supposed nutrients, which replaces those that are easily lost through excessive sweating and physical activity. Another popular dish is ginseng chicken noodles.

Botany

A small perennial herb, 30–80 cm high with fleshy, fusiform, aromatic, thick and branched roots with characteristic horizontal lines (Plates 1 and 2). The stem is cylindrical, smooth, green, often with a tinge of red, regularly divided at the top into three petioles, with a flower stalk in their centre. The petiole is cylindrical, smooth and swollen at the base. Leaves borne in whorls, 3–4, palmately compound; leaflets 5, long-petioled, obovate, 7–20 cm long, abruptly acuminate to caudate, margin serrate. Umbel solitary in the middle of leaf whorls. Flowers small, yellowish green, bisexual, in single terminal umbels; sepals 5 minute, petals 5 ovate, imbricate; stamens 5 with oblong anthers; ovary 2–3 celled, inferior; styles 2 reflexed and persistent. Fruit a drupe, red, globose, about 5 mm in diameter.

Plate 1 Fresh ginseng roots

Plate 2 Preserved ginseng roots

Nutritive/Medicinal Properties

Root Nutrient/Phytochemicals

Ginseng root was reported to contain ginseng saponins, ginseng oils and phytosterol, carbohydrates and sugars, organic acids, nitrogenous substances, amino acids and peptides, vitamins and minerals, certain enzymes (Hou 1977), saponins, polyphenols, polyacetylenes, alkaloids and polysaccharides (Jeon et al. 2011). Among these, ginseng saponins called ginsenosides or panaxosides, triterpenes of dammarane and oleanane structures, were proven to be the principal and most active constituents (Jeon et al. 2011; Park et al. 2005a).

Lin (1961) reported the following constituent of ginseng: sugars – glucose, arabinose, sucrose, rhamnose, sterols such as stigmasterol, β-sitosterol, high molecular weight fatty acids (panax acids) fatty acid esters and the triterpenoid genin oleanolic acid.

Free amino acids (mg/100 g) found in washed fresh ginseng roots were aspartic acid 78.05 mg, threonine 52.14 mg, serine 244.21 mg, glutamic acid 57.20 mg, proline 43.63 mg, glycine 172.20 mg, alanine 58.71 mg, methionine 45 mg, isoleucine 72.12 mg, leucine 54 mg, tyrosine 123.31 mg, phenylalanine 158.18 mg, β-alanine 113.87 mg, lysine 138.53 mg, histidine 30.09 mg, arginine 330.68 mg and total amino acids 4,770.42 mg (Lee et al. 2009c). After six repeated boiling and the addition of sugar to boiled ginseng roots (Jung Kwa process), crude saponin of Jung Kwa (JKG6) increased fourfold, while ginsenoside RF and RD contents increased 77- and 16-fold more than raw ginseng, respectively; other ginsenosides (RB_1, RB_2, RB_3, Rc, Re, Rg_1, Rg_2, Rg_3, Rh_1 and Rh_2) decreased. Concomitant with the number of boiling repeats, crude protein and total free amino acids decreased by 84.9 % and 94.7 % of raw ginseng in JKG but increased by 98.2 % and 78.9 % in JKGS (solution), respectively. The arginine content in the last boiled ginseng, JKG 6, decreased 49.18-fold, while γ-aminobutyric acid and two unknown compounds not present in fresh ginseng were formed as intermediate products during the Jung Kwa heating process. The γ-aminobutyric content was 34.13 mg/100 g in JKG 6. The carbohydrate and ginsenoside profile of wild and cultivated ginseng root was reported as follows: soluble sugars 34.42, 26 mg/g; starch 14.38, 32.78 mg/g; polysaccharides 43.61, 51.22 mg/g; pectin 13.48, 10.61 mg/g; total ginsenosides 24.06,15.08 mg/g; protopanaxatriol 8.36, 5.16 mg/g; and protopanaxadiol 15.69, 9.92 mg/g, respectively (Zhang et al. 2013a). Content (mg/g) of ginsenosides in wild and cultivated at year 6 growth stage was reported as follows: Rg_1 3.61, 2 mg; Re 4.29, 2.82 mh; Rf 1.32, 0.55 mg; Rb_1 6.14, 4.21 mg; Rc, 5.38, 4.01 mg; Rb_2 4.40, 4.05 mg; and Rd 1.84, 1.88 mg, respectively.

Monosaccharide, D-fructose and D-glucose were identified, and the total amount of these monosaccharides in the dried ginseng root was 1.5 %; disaccharides were present in 3.3 % amount, and sucrose and maltose were separated as crystals (Takiura and Nagakawa 1963a). Four kinds of trisaccharide, A, B, C and D, were found in the aqueous digest solution of ginseng root (Takiura and Nakagawa 1963b). Trisaccharide A was identified as *O*-α-D-glucopyranosyl-(1→2)-*O*-β-D-fructofuranosyl-(1→2)-β-D-fractofuranoside and B as *O*-α-D-glucopyranosyl- (1→6)-*O*-α-D-glucopyranosyl- (1→4)-*O*-α-D-glucopyranose. Trisaccharide C was found to be α-Maltulosyl-β-D-fructofuranoside (Takiura and Nakagawa 1963c).

Lin (1961) reported the presence of sugars glucose, arabinose, sucrose and rhamnose; sterols such as stigmasterol; β-sitosterol; high molecular weight fatty acids (panax acids); fatty acid esters; and the triterpenoid genin oleanolic acid. The following compounds were found in ginseng roots: fatty acid methyl esters, fatty acids, β-sitosterol, esters of β-sitosterol and fatty acids (palmitic and linoleic), 6-*O*-acyl derivatives of β-sitosterol glucoside and β-sitosterol glucoside and ginsenosides RG_1, Rf, Rc, RB_2, RB_1 and RO as main components and ginsenosides Rd, NG-R2 and Z-R1 as minor components (Malinovskaya et al. 1991). The following fatty acids (μg/g) were found in ginseng: myristic acid 0.16 μg, pentadecanoic acid 0.47 μg, palmitic acid 13.93 μg, palmitoleic acid 0.71 μg,

heptadecanoic acid 0.36 μg, stearic acid 1.41 μg, oleic acid 3.88 μg, linoleic acid 28.22 μg, α-linolenic acid 1.71 μg, arachidic acid 0.45 μg and eicosadienoic acid 0.52 μg (Zhang et al. 2013b). Nineteen fatty acids were identified in ginseng and the major components were unsaturated fatty acids such as 9,12-octadecadienoic acid and 9-octadecenoic acid (Yang et al. 2007). Twenty fatty acid compounds were isolated and identified from several ginseng varieties (Chen et al. 2010). The major components were (*Z*,*Z*)-9,12-octadecadienoic acid, hexadecanoic acid and (*Z*,*Z*,*Z*)-9,12,15-octadecatrienoic acid, but the content varied with varieties: (*Z*,*Z*)-9,12-octadecadienoic acid was 47.896 % in Damaya, 50.901 % in Ermaya, 50.254 % in Yuanbangyuanlu and 49.456 % in Changbo; hexadecanoic acid content was 12.370 % in Damaya, 12.535 % in Ermaya, 12.614 % in Yuanbangyuanlu and 11.983 % in Changbo; (*Z*,*Z*,*Z*)-9,12,15-octadecatrienoic acid content was 10.407 % in Damaya, 12.487 % in Ermaya, 12.026 % in Yuanbangyuanlu and 12.026 % in Changbo.

Studies found that most free amino acids were decreased significantly by steam treatment, with the greatest reduction observed in ginseng steamed at 120 °C (SG) (Cho et al. 2008). The total content of free amino acids, 17.9 mg/g in white ginseng (WG), was reduced to 12.2 mg/g in red ginseng (RG, ginseng steamed at 100 °C) and 2.79 mg/g in SG. As for arginine, the most predominant amino acid in ginseng, the content, 10.4 mg/g in WG, decreased significantly to 1.38 mg/g in SG. In particular, β-*N*-oxalyl-*L*-α,β-diaminopropionic acid (β-ODAP), a well-known neurotoxin, was reduced by 92.9 % in SG. In contrast, the level of Maillard reaction products (MRPs), powerful antioxidants, increased with steam treatment, indicating that the reduction of most amino acids was attributed to the extent of the Maillard reaction.

Phenolic Compounds/Metabolites

Six types of phenolic acids – *p*-hydroxybenzoic acid, vanillic acid, syringic acid, *p*-coumaric acid, ferulic acid and sinapic acid – were identified in ginseng adventitious roots irradiated with red (630 nm) and blue (465 nm) LED light or fluorescent lamp (FL) light (Park et al. 2013c). The insoluble (bound form) phenolic acid levels were higher than the soluble (free and esterified forms) levels in all ginseng samples. The major portion of phenolic acids in ginseng roots consisted of ferulic, *p*-coumaric and *p*-hydroxybenzoic acids. Compared to white FL-irradiated ginseng roots, roots irradiated with two different LED lights had higher concentrations of total phenolic acids, which increased by 87 % in blue LED light-irradiated ginseng roots. A significant increase was presented only in the *p*-coumaric acid content in red LED light ginseng roots, while *p* -coumaric and ferulic acids were markedly increased in blue LED light-irradiated ginseng roots. Forty-six metabolites comprising 35 hydrophilic and 11 lipophilic metabolites were identified from ginseng adventitious root extracts irradiated with florescent lamp and red and blue LED lights. Hydrophilic compounds identified included pyruvic acid, lactic acid, glycolic acid, phosphoric acid, succinic acid, glyceric acid, fumaric acid, shikimic acid, citric acid, quinic acid, malic acid, ethanolamine, glycerol, inositol, 4-aminobutyric acid, alanine, valine, isoleucine, proline, serine, threonine, β-alanine, tryptophan glycine, asparagine, glutamine, aspartic acid, methionine, glutamic acid, phenylalanine, pyroglutamic acid, xylose, fructose, galactose and sucrose; lipophilic metabolite compounds detected included hexadecanoic acid, *cis*,*cis*-9,12-octadecadienoic acid, *cis*-9-octadecadienoic acid, octadecanoic acid, eicosanoic acid, docosanoic acid, α-tocopherol, campesterol, stigmasterol, β-sitosterol and β-amyrin. LED light-irradiated ginseng roots had higher sucrose and lower amino acids compared to florescent lamp-irradiated ginseng roots. On alkaline hydrolysis, 13 lipophilic compounds comprising 6 policosanols (C20-ol (eicosanol), C21-ol (heneicosanol), C22-ol (docosanol), C23-ol (tricosanol), C24-ol (tetracosanol), C28-ol (octacosanol)), 5 phytosterols (campesterol, cholesterol, stigmasterol, β-sitosterol, β-amyrin) and two tocopherols (α-tocopherol, β-tocopherol) were identified in ginseng roots irradiated with different light emission spectra. The most notable findings were in the α-tocopherol and β-amyrin content, which

was 2.54- and 1.94-fold higher in blue LED light-irradiated ginseng roots compared to those in FL light-irradiated ginseng roots.

Total phenolic acids in white and red ginsengs were 27.2 and 26.8 mg/100 g, respectively (Jung et al. 2002). Seven free phenolic acids were identified and their total contents in white and red ginsengs were 4.70 and 4.14 mg/100 g, respectively. *trans*-Ferulic acid was the predominant free phenolic acid, representing 47.9 and 57.7 % of total free phenolic acids in white and red ginsengs, respectively. Esterified phenolic acids represented 71.9 and 77.1 % of total phenolic acids in white and red ginsengs, respectively. The most predominant esterified phenolic acids were *cis*-ferulic acid and *trans*-ferulic acid. Total insoluble-bound phenolic acid contents in white and red ginsengs were 2.93 and 1.99 mg/100 g, respectively. Ferulic acid (*cis* and *trans* isomers) were also the major insoluble-bound phenolic acids. Eight aromatic acids were found in white ginseng roots: salicylic acid 4.30 ppm, cinnamic acid 18.2 ppm, vanillic acid 4.22 ppm, gentisic acid trace, syringic acid 6.69 ppm, *p*-coumaric acid 13.3 ppm n, ferulic acid 21.9 ppm and caffeic acid 24.3 ppm (Park et al. 1994). The phenolic compounds vanillic acid, caffeic acid, ferulic acid, *p*-coumaric acid, protocatechuic acid and maltol were identified in the ethyl acetate fraction of Korean red ginseng methanol extract (Wee et al. 2010). Ginseng was found to contain choline in 0.100.2 % weight of roots (Takatori et al. 1963).

Studies in a bioreactor found that CO_2 induced accumulation of total phenolics in a concentration- and duration-dependent manner in ginseng roots in suspension culture (Ali et al. 2005a). Total phenols, flavonoids and 1,1-diphenyl-2-picrylhydrazyl (DPPH) activity increased by 2.5 % CO_2 after 45 days compared to control in *P. ginseng* roots which indicated that phenolics compounds played an important role in protecting the plants from CO_2. Also high CO_2 progressively stimulated the activities of glucose 6 phosphate dehydrogenase (G6PDH), shikimate dehydrogenase (SKDH), phenylalanine ammonia lyase (PAL), cinnamyl alcohol dehydrogenase (CAD), caffeic acid (CA) peroxidase and chlorogenic acid (CGA) peroxidase after 15, 30 and 45 days. Increased CO_2 levels resulted in increases in accumulation of total protein (45 %), nonprotein thiol (NPSH) (30 %) and cysteine contents (52 %) after 45 days compared to control, and increased activities of beta-glucosidase (GS) and polyphenol oxidase (PPO) in ginseng roots indicated that they played an important role in protecting the plants from CO_2. Ali et al. (2005b) also demonstrated that methyl jasmonate or salicylic acid treatments in bioreactor suspension culture caused an increase in the carbonyl and hydrogen peroxide (H_2O_2) contents, total phenolic, flavonoid, ascorbic acid, nonprotein thiol (NPSH) and cysteine contents and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical reducing activity. The highest total phenolics (62 %), DPPH activity (40 %), flavonoids (88 %), ascorbic acid (55 %), NPSH (33 %) and cysteine (62 %) contents compared to control were obtained after 9 days in salicylic acid-treated roots. The activities of glucose 6-phosphate dehydrogenase, phenylalanine ammonia lyase and substrate-specific peroxidases (caffeic acid peroxidase, quercetin peroxidase and ferulic acid peroxidase) were higher in methyl jasmonate-treated roots than the salicylic acid-treated ones. Increased shikimate dehydrogenase, chlorogenic acid peroxidase and beta-glucosidase activities and proline content were observed in salicylic acid-treated roots than in methyl jasmonate-treated ones. Cinnamyl alcohol dehydrogenase activity remained unaffected by both methyl jasmonate and salicylic acid. These results strongly indicated that methyl jasmonate and salicylic acid induced the accumulation of phenolic compounds in ginseng root by altering the phenolic synthesis enzymes.

Ginseng Oil/Volatiles

Takahashi et al. (1961) reported the presence of β-sitosterol, β-sitosterol glucoside daucosterin, phytosterin, panaquilon, panaxsapogenol, panaxin, stearic acid, palmitic acid and linoleic acid in the essential oil of ginseng roots. The main constituents in *P. ginseng* essential oil were spathulenol (11.55 %) and 2-*epi*-(E)-β-caryophyllene (10.88 %) (Smiglielski et al. 2006). Forty-six compounds were found in ginseng volatile oil, and the major compounds were

2,2′-methylene-bis[6-(1,1-dimethylethyl)-4-methylphenol (10.56 %),1,2-benzenedicarboxylic acid diisooctyl ester (6.52 %),7,11-dimethyl-3-methylene-1,6,10-dodecatrie (5.45 %) and 13-tetradecen-1-ol acetate (4.14 %) (Yang et al. 2007). Thirty-six terpenoids were tentatively identified in ginseng volatile oil (Qiu et al. 2008). It was found that the relative abundances of α-cadinol, α-bisabolol, thujopsene and *n*-hexadecanoic acid significantly increased with increase in age. A total of 47 volatile were identified in fresh, white and red ginseng (Abd El-Aty et al. 2008). Fresh ginseng was characterised by a high proportion of 3-acetyl-1-(3,4-dimethoxyphenyl)- 5-ethyl-4,5-dihydro-7,8-dimethoxy-4-methylene-3H-2,3-benzodiazepine (64.24 %) and 23,24-dinor-3-oxolean-4,12-dien-28-oic acid (21.42 %); 2-furanmethanol (20.26 %) and 3-hydroxy-2-methyl-4H-pyran-4-one (17.95 %) were detected as the major components in white ginseng, while the main components of the red ginseng were found to be 1,2-benzenedicarboxylic acid dibutyl ester (16.27 %) and 2-furanmethanol (13.82 %). Main volatile compounds of ginseng species including *Panax ginseng* were sesquiterpenes, such as bicyclogermacrene, (*E*)-β-farnesene, β-panasinsene, calarene, α-humulene, β-elemene, etc. (Cho et al. 2012). In particular, α-selinene, α-terpinolene, β-bisabolene, β-phellandrene, β-sesquiphellandrene, zingiberene, germacrene D, limonene, α-gurjunene, (*E*)-caryophyllene, δ-cadinene, (E)-β-farnesene, α-humulene, bicyclogermacrene, longiborn-8-ene, β-neoclovene and (+)-spathulenol were mainly associated with the difference between *P. ginseng* and *P. notoginseng* versus *P. quinquefolius* species. In contrast, the discrimination between *P. ginseng* and *P. notoginseng* could be constructed by hexanal, 2-pyrrolidinone, (*E*)-2-heptenal, (*E*)-2-octenal, heptanal, isospathulenol, (*E*,*E*)-2,4-decadienal, 3-octen-2-one, benzaldehyde, 2-pentylfuran and (E)-2-nonenal.

Polysaccharides/Proteinaceous Compounds and Enzymes

Ginseng was found to have β-amylase (Yamasaki et al. 1989). The molecular weight of the enzyme was estimated to be 63 kDa, and it was of 512 amino acid residues. The content of neutral sugars was 8.5 %, and no amino sugar was detected. A superoxide dismutase (SOD) with the molecular weight of 31,079 was purified as a homodimer from *Panax ginseng* (Li et al. 2010a). Arginase was purified from ginseng roots (Hwang et al. 2001). Specific activities of the enzyme in sliced ginseng roots were increased by plant hormones such as GA_3, IAA, kinetin and putrescine, whereas the activities of the purified enzyme were unaffected by putrescine. Increases in arginase activities by these plant hormones could affect metabolism of polyamine intracellularly. Han et al. (2010) found that the expression of two squalene epoxidase genes *PgSQE1* and *PgSQE2* were regulated in a different manner and that *PgSQE1* will regulate ginsenoside biosynthesis, but not that of phytosterols in *P. ginseng*. Squalene epoxidase catalysed the first oxygenation step in phytosterol and triterpenoid saponin biosynthesis. RNA interferences of *PgSQE1* in transgenic *Panax ginseng* completely suppressed the *PgSQE1* transcription and resulted in the reduction of ginsenoside production but rather stimulated phytosterol accumulation. The following nucleosides and free bases of nucleic acids uridine, guanine, adenosine, adenine and uracil were found in white ginseng roots (Hiyama et al. 1978). A metal binding tetradecapeptide was isolated from ginseng root (Kajiwara et al. 1996). The ginseng tetrapeptide H-L-Val-γ-D-Glu-D-Arg-Gly-OH was found to have a rigid backbone based on three intramolecular hydrogen bonds between D-Arg NH and L-VAL CO, between Gly NH and D-Glu CO and between Gly NH and Gly CO (Ishizu et al. 1998). A novel tetradecapeptide was purified from ginseng polypeptides, and its structure had the amino acid sequence of Lys-Ser-Leu-Thr-Leu-Thr-Ser-Ser-Leu-Ser-Tyr-Thr-Asp-Ser (Luo et al. 2013).

From the roots of the Chinese ginseng, a protein designated panaxagin with ribonuclease activity was isolated (Ng and Wang 2001). The purified protein was composed of two identical subunits, each with a molecular weight of 26 kDa. Its N-terminal amino acid sequence exhibited sites of similarity with the sequences of plant ribosome-inactivating proteins and fungal ribonucleases. A novel glycolipoprotein named gintonin was isolated from ginseng (Pyo et al.

2011). Gintonin existed in at least six different forms. The native molecular weight of gintonin was about 67 kDa, but its apparent molecular weight was about 13 kDa, indicating that gintonin might be a pentamer. Gintonin was rich in hydrophobic amino acids with glucose and glucosamine as its main carbohydrates and with lipid components linoleic, palmitic, oleic and stearic acids. Gintonin was found to be novel lysophosphatidic acids (LPAs)-ginseng protein complex (Shin et al. 2012) and lysophosphatidic acid (LPA) receptor-activating ligand (Hwang et al. 2012a, b).

A hypoglycaemic principle, panaxan B, obtained from ginseng roots, was shown to be a peptidoglycan with M_r of about 1,800,000 and mainly composed of α-1→6 linked D-glucopyranose residues with branching at the C-3 position, the ratio of terminals, branching positions and intermediate units being about 1:1:1.8 (Tomoda et al. 1985). Four glycans, panaxans I, J, K and L, were isolated from ginseng roots (Oshima et al. 1985). Five glycans, panaxans Q, R, S, T and U, were isolated from ginseng roots (Konno et al. 1985). Two lignans named gomisin N and gomisin were isolated from hexane-soluble fraction of Korean red ginseng (Huh et al. 1990). Chemical composition of ginseng polysaccharide fractions were 85.0 % carbohydrate and 15.0 % protein for the neutral fraction and 28.4 % carbohydrate, 10.0 % protein and 29.0 % uronic acid for the acidic fraction (Kim et al. 1990). Kim et al. (1999a) isolated antithrombin active heteropolysaccharide with molecular mass of 177 kDa from red ginseng. It contained uronic acid moiety (40.2 %), sulfate group (9.2 %) and protein (1.5 %) in addition to neutral sugar of rhamnose, mannose, galactose, arabinose, glucose, fucose and xylose in a molar ratio of 1.00: 0.88:0.86:0.78:0.70:0.33:0.22. First- and third-grade 6-year-old Korean ginseng starches showed typical biphasic differential scanning calorimetry (DSC) endotherm, while second-grade ginseng starch revealed monophasic DSC endotherm with relatively narrow transition temperature (Koo et al. 2005). First- and third-grade ginseng starches showed higher degree of retrogradation and faster retrogradation rate than second-grade ginseng starch.

Water-soluble polysaccharides isolated from ginseng roots were completely fractionated into two neutral fractions (WGPN and WGPA-N) and six acidic fractions (WGPA-1-RG, WGPA-2-RG, WGPA-1-HG, WGPA-2-HG, WGPA-3-HG and WGPA-4-HG) (Zhang et al. 2009). WGPN was a starchlike glucan; WGPA-N was a mixture of starchlike glucan and arabinogalactan; and WGPA-1-RG and WGPA-2-RG were composed of major neutral sugars and minor acidic sugars that belong to the type-I rhamnogalacturonan (RG-I)-rich pectins, while fractions WGPA-1-HG to WGPA-4-HG were mainly composed of galacturonic acid (GalA, 62.4–92.1 %) and have been identified to be homogalacturonan (HG)-rich pectins with different degrees of methyl-esterification, ranging from 0 to 30 %. PG-F2, an acidic polysaccharide with high uronic acid content, was purified from the root of *Panax ginseng* (Lee et al. 2004a, 2006a). PG-F2 was found to be a pectin-type polysaccharide with a mean molecular weight of 1.2×10^4 Da and consists primarily of galacturonic and glucuronic acids along with rhamnose, arabinose and galactose as minor components.

Five rhamnogalacturonan I (RG-I) domains, RG-I-1, RG-I-2, RG-I-3A, RG-I-3B and RG-I-4, were isolated from ginseng pectin by endo-polygalacturonase hydrolysis (Yu et al. 2010). The five domains all contained galacturonic acid, rhamnose, galactose and arabinose as main components, and their rhamnose/galacturonic acid was from 0.26 to 0.64, among the range of RG-I. The molecular weights of RG-I-1 (5 kDa), RG-I-2 (4 kDa) and RG-I-3B (6 kDa) were smaller than those of RG-I-3A (45 kDa) and RG-I-4 (60 kDa). RG-I-2 and RG-I-3B contained RG-I domains linked with highly methyl-esterified and acetylated homogalacturonan domains and the side chains probably belonging to type I and type II arabinogalactans, while RG-I-3A and RG-I-4 may have the side chains of type I arabinogalactans. 4-*O*-methyl-β-D-glucuronic acid residues were present at nonreducing terminals of RG-I-2.

Two pectic polysaccharides, named as GP50-dHR (56.0 kDa) and GP50-eHR (77.0 kDa), were purified from hot water extract of ginseng (Baek et al. 2010). Both polysaccharides had common

structural features of homogalacturonan backbone with hairy regions of rhamnogalacturonan type I. Arabinose-rich side chains with abundant branch points were unique in GP50-eHR and may contribute to a greater antirotavirus effect of GP50-eHR than GP50-dHR. The acidic polysaccharide portion of the plant (WGPA) was found to contain arabinogalactan-, type-I rhamnogalacturonan (RG-I)- and homogalacturonan (HG)-rich pectins (Wang et al. 2010a). The ginseng pectic fraction WGPA-2-RG was identified to have rhamnogalacturonan-I structure (Zhang et al. 2012). WGPA-2-RG had a small backbone and long arabinogalactan-II side chains. Most of the galactose were close to molecular core and all arabinose were on the molecular surface. Arabinose residues were important to lymphocyte proliferation and NO production. Sugar composition of polysaccharide fractions from ginseng was as follows: for WGPA fraction 34.4 % uronic acid, 18.5 % glucose (Glu), 15.5 % arabinose, 18 % galactose (Gal), 44.2 % Gal A, 2.5 % rhamnose and Glu A 1.3 % (Zhang et al. 2009; Wang et al. 2014a); for WGPA-A fraction 43.5 % uronic acid, 3.7 % glucose, 22.7 % arabinose, 13.3 % galactose, 51.7 % Gal A, 6 % rhamnose, mannose 0.5 % and Glu A 2.2 %; for WGPA-N fraction 0 % uronic acid, 66.3 % glucose, 15.7 % arabinose and 18 % galactose (Wang et al. 2014a). Cell-cultured ginseng polysaccharides (CCGPS) consisted of glucose, rhamnose, arabinose, xylose, mannose and galacturonic acid (Ding et al. 1993). Comparing with GPS (ginseng polysaccharide), the percentage of rhamnose, arabinose, xylose and galactose were higher than that of GPS, whereas mannose and glucose were less. The starch was 50–S0 % in the cultivated GPS. However, no starch was found in the CCGPS in which two monosomes of water-soluble polysaccharides PCl and PC2 with molecular weight 122,000 and 2S,000 D, respectively, were obtained. A major protein GMP, composed of two subunits of approximately 28 kDa, was isolated from ginseng root (Yoon et al. 2002). It was found that carbohydrates were bound non-covalently to GMP whose amino acid composition analysis showed high amounts of acidic amino acids.

An acidic polysaccharide ginsan, with a molecular weight of 150,000, devoid of lectin properties, was purified from *Panax ginseng* (Lee et al. 1997). Another acidic polysaccharide ginsenan S-IIA was isolated from ginseng root (Sonoda et al. 1998). Two neutral polysaccharide fractions named GPII and GPIII, with a molecular weight of 3×10^5 and 4×10^5, respectively, and comprising mainly glucose, were obtained from boiled ginseng extracts (Luo and Fang 2008). GP II was composed of 60.06 % (1→)-glycosidic linkage or (1→6)-glycosidic linkage and 39.94 % (1→3)-glycosidic linkages, and GPIII was composed of 16.23 % (1→)-glycosidic linkage or (1→6)-glycosidic linkage, 25.98 % (1→2)-glycosidic linkages and 57.79 % (1→3)-glycosidic linkages. Polysaccharides PG-F2, a pectin-type polysaccharide, and PG-HMW, an arabinogalactan, were isolated from *Panax ginseng* (Lee et al. 2009b). Ginsan, an acidic polysaccharide, was extracted from ginseng roots (Ivanova et al. 2006; Shim et al. 2010; Hwang et al 2011; Park et al. 2011). The oligosaccharides were identified as maltose, maltotriose, maltotetraose, maltopentaose, maltohexaose and maltoheptaose from 30 % ethanol elution of ginseng roots (Wang et al. 2010b). A homogeneous polysaccharide (PGPW1) from ginseng root with molecular weight 3.5×10^5 Da was found to contain glucose, galactose, mannose and arabinose in the molar ratio of 3.3:1.2:0.5:1.1 (Li et al. 2012a). Water-soluble ginseng oligosaccharides (designated as WGOS) with a degree of polymerisation ranging from 2 to 10 were obtained from warm water extract of ginseng roots and fractionated into five purified fractions (i.e. WGOS-0, WGOS-1, WGOS-2, WGOS-3 and WGOS-4) (Wan et al. 2012). α-Glcp-(1→6)-α-Glcp, α-Glcp-(1→6)-α-Glcp-(1→4)-α-Glcp, α-Glcp-(1→6)-α-Glcp-(1→6)-α-Glcp-(1→4)-α-Glcp and other six maltooligosaccharides (i.e. maltopentaose, maltohexaose, maltoheptaose, maltooctaose, maltononaose and maltodecaose) were detected in ginseng. Four glycoproteins were isolated from ginseng root (Wang et al. 2013b). Results of studies by Hu et al. (2013) found that the recombinant dammarenediol synthase (DS) protein could increase the production of dammarenediol and the expression of DS played a vital role in the biosynthesis of ginsenosides in *P. ginseng*. Ginseng root polysaccharide

(PGP2a) an acidic protein–polysaccharide, with molecular weight of 3.2×10^4 Da, was found to consist of galactose, arabinose, glucose and galacturonic acid in the molar ratio of 3.7:1.6:0.5:5.4, respectively (Li et al. 2014).

Saponins

To date, approximately 70 kinds of ginsenosides had been isolated from *P. ginseng* (Cho et al. 2013a). Most of them were saponins of protopanaxadiol (diol, PPD) and protopanaxatriol (triol, PPT), which were aglycones of dammarane-type triterpenoids. Only a few ginsenosides, such as ginsenoside Ro, had oleanolic acid as the aglycone. Ginsenosides were primarily classified into two groups, the 20(*S*)-protopanaxadiol (PD) and the 20(S)-protopanaxatriol (PT) (Popovich et al. 2012). These two types of ginsenoside comprised the bulk of the reported ginsenosides. The PD type included commonly reported ginsenosides Rb_1, Rb_2, Rc and Rd and rarer types known as Rg3 and Rh2, while the PT type includes Re, Rf, Rg_1, Rg_2 and Rh_1. The third type of ginsenoside had been detected in ginseng and had been referred to as oleanane type.

In *Panax ginseng*, both ginsenosides and phytosterols were suggested to be derived from the precursor 2,3-oxidosqualene (Haralampidis et al. 2002; Lee et al. 2004c; Han et al. 2010). Triterpenoid saponins were reported to be synthesised via the isoprenoid pathway by cyclisation of 2,3-oxidosqualene to give primarily oleanane (beta-amyrin) or dammarane triterpenoid skeletons (Haralampidis et al. 2002). Lee et al. (2004c) demonstrated that squalene synthase (PgSS1) was a key regulatory enzyme not only for phytosterol but also for triterpene biosynthesis and overexpression of *PgSS1* conferred the hyperproduction of triterpene saponins to *P. ginseng*. The enzymes cycloartenol synthase (CS) and dammarenediol synthase (DS) were responsible for ginsenoside and phytosterol biosynthesis, respectively (Liang et al. 2009). They found that antisense inhibition of cycloartenol synthase gene following suppression in transgenic ginseng hairy roots resulted in decreased phytosterol levels and enhanced ginsenoside levels. Earlier Kushiro et al. (1997) reported that (RS)-[3-3H]-2,3-oxidosqualene was converted into (20S)-dammarenediol and not to (20R)-dammarenediol by a microsomal fraction prepared from *P. ginseng* hairy root (Kushiro et al. 1997).

A compound named panaquilon was extracted from ginseng root on hydrolysis with concentrated sulfuric acid to yield panacone (Garriques 1854). The saponin fraction of ginseng extract on acid hydrolysis yielded panaxsapogenol (Kondo and Tanaka 1915; Kondo and Yamaguchi 1918; Kondo and Amano 1920). Yonekawa (1926) isolated a glycoside called ginsenin, and Kotake (1930) isolated a glycoside called panaxin which on acid hydrolysis gave a prosapogenin α-panaxin which on further acid hydrolysis afforded glucose and a chlorinated aglucone (Hou 1977). Panaxatriol, a genin of ginsensoide Rg_1, was isolated in high yield from ginseng callus (Furuya et al. 1970).

Eight saponins and small amounts of panaxadiol, panaxatriol, daucosterol, mannitol, sucrose and glucose were isolated from the ethanol-insoluble aqueous extract of ginseng (Kaku et al. 1975). A prosapogenin and a sapogenin (panaxadiol) $C_{30}H_{52}O_3$, m.p. 250°, were isolated from the roots of *P. ginseng* (Fujita et al. 1962). The genuine sapogenin of Rg1 was found to be 20S-protopanaxatriol (=6α-hydroxy-20S-protopanaxatriol) (Iida et al. 1968). On hydrolysis with dilute mineral acid, ginseng saponins ginsenosides Rb_1, Rb_2, Rb_3, Rc and Rd yielded panaxadiol, and ginsenosides Re, Rf, Rg_1 and Rg_2 and 20-glucoginsenoside Rf afforded panaxatriol (Sakamoto et al. 1975).

A new panaxadiol, neopanaxadiol, was obtained from the acid hydrolysate of the total ginsenosides of *Panax ginseng*, and its structure was elucidated to be dammar-(*E*)-20(22)-ene-3β,12β,25-triol (Tao et al. 2009). A comparative study suggested that panaquilon (Garriques 1854), panaxin (Kotake 1930) and ginsenin (Yonekawa 1926) would be similar saponins, while panacon (Garriques 1854) and α-panaxin (Kotake 1930) would be identical with their prosapogenin, m.p. 330°C. The active principles of *Panax ginseng* were not panaquilon and panax acid as previously considered (Yamada 1955). Elyakov et al. (1962, 1965a) isolated from gin-

seng root methanolic extracts a series of sugar-linked compounds called panaxosides A and B in 1962 and panaxosides C, D, E and F in 1964 (Elyakov et al. 1964, 1965b; Uvarova et al. 1965). When panaxosides D, E and F were hydrolysed, panaxadiol was formed as the main product of the decomposition of the genins, and hydrolysis of saponin glycosides panaxosides A, B and C yielded panaxatriol. Panaxosides D and F were pentaglucoside and hexaglucoside, respectively (Uvarova et al. 1965). Panaxoside E contained one arabinose and four glucose residues. Among the decomposition products of the genin obtained in the acid hydrolysis of panaxosides D, E and F, panaxadiol and panaxagenin B were identified. Panaxoside C was found to be a tetroside with glucose and rhamnose in a ratio of 3:1 in the carbohydrate moiety and panaxoside B to be trioside with two carbohydrate side chains with glucose fragments connected by a 1→2 bond (Uvarova et al. 1970). The methylation of panaxoside C afforded a hydrolysate containing two terminal methylated monosaccharides: 2, 3, 4, 6-tetra-*O*-methyl-D-glucose and 2, 3,4-tri-*O*-methyl-L-rhamnose and also 3,4, 6-tri-*O*-methyl-D-glucose. The extract of a ginseng suspension cell culture contained as the main components β-sitosterol, β-sitosterol β-D-glucoside and an oleanolic acid glucoside (Uvarova et al. 1987). A feebly polar fraction of the crude glycosidic fraction of the methanol ginseng extract afforded a mixture of β-sitosterol and palmitoyl- and linoleoyl-B-D-glucosides in addition to the compounds isolated earlier (Uvarova et al. 1987). Thus, a cell culture of ginseng (strain BIO-2) produced, in addition to substances isolated previously, 6-*O*-acyl derivatives of β-sitosterol β-D-glucoside.

A sapogenin named panaxadiol was isolated from ginseng root (Shibata et al. 1962). panaxadiol $C_{30}H_{52}O_3$ was determined to be tetracyclic triterpene of dammarane series having hydroxyls at the 3- and 12-positions and trimethyltetrahydropyrane ring at $C_{(17)}$ (Shibata et al. 1963a, b). Prosapogenin was obtained from ginsenosides RB_1, Rb_2 and Rc by partial hydrolysis with hot aqueous acetic acid (Shibata et al. 1966a). Dilute acid hydrolysis of ginsenosides Rb_1, Rb_2 and Rc yielded protopanaxadiol and panaxadiol (Shibata et al. 1966b). Protopanaxadiol and panaxadiol from ginseng were found to have a C/D *trans*-17α-H structure, and dihydro protopanaxadiol was found to be correlated stereochemically to dammaranediol-I (Tanaka et al. 1966). The saponins ginsenosides Ro, Rb_1, Rb_2, Rc and Rd were isolated from ginseng roots (Sanada et al. 1974a). The structures of ginseng root ginsenoside Ro was identical with chikusetsusaponin V, isolated from *P. japonicum*, while ginsenoside Rb_1 was identical with saponin-D isolated from *P. pseudoginseng* subsp. *himalaicus* var. *angustifolius*. The structure of Rb_1 was established as 20*S*-protopanaxadiol-3-[*O*-β-D-glucopyranosyl (1→2)-β-D-glucopyranoside]-20-[*O*-β-glucopyranosyl(1→6)-β-D-glucopyanoside]. The structures of ginsenosides Rb_2, Rc and Rd were established respectively as 20*S*-protopanaxadiol-3-[*O*-β-D-glucopyranosyl(1→2)- β-D-glucopyranoside]-20-[*O*-α-L-arabinopyranosyl(1→6)-β-D-glucopyranoside];20*S*-protopanaxadiol-3-[*O*-β-D-glucopyranosyl (1→2)-β-D-glucopyranoside]-20-[*O*-α-L-arabinofuranosyl (1→6)- β-D-glucopyranoside]; and 20*S*- protopanaxadiol-3-[*O*-β-D-glucopyranosyl (1→2)-β-D-glucopyranoside]-20-[*O*-β-D-glucopyranoside]. The structures of ginsenosides Re, Rf and Rg_2 were elucidated as 20*S*-protopanaxatriol-6-[*O*-α-L-rhamnopyranosyl (1→2)-β-D-glucopyranoside]-20-*O*-β-D-glucopyranoside; 20*S*-protopanaxatriol-6-*O*-β-D-glucopyranosyl (1→2)-β-D-glucopyranoside; and 20*S*-protopanaxatriol-6-*O*-α-L-rhamnopyranosyl (1→2)-β-D-glucopyranoside, respectively (Sanada et al. 1974b).

Crude hesperidinase hydrolysed ginsenoside Rg_1 to give its genuine sapogenin, 20(*S*)-protopanaxatriol, and glucose in almost quantitative yield (Kohda and Tanaka 1975), whereas a mixture of ginsenosides Rb_1, Rb_2 and Rc gave compound K (=20-*O*-β-glucosyl-20(*S*)- protopanaxadiol) as a main product with this crude enzyme preparation. The structures of ginseng root ginsenoside Rb_3 and 20-glucoginsenoside Rf were established to be 20*S*-protopanaxadiol-3-[*O*-β-D-glucopyranosyl (1→2)-β-D-lucopyranoside]-20-[*O*-β-D-xylopyranosyl (1→6)-β-D-glucopyranoside] and 20*S*-protopanaxatriol-6-[*O*-β-D-glucopyranosyl (1→2)-β-D-glucopyranoside]-

20-*O*-β-D-glucopyranoside, respectively (Sanada and Shoji 1978). A saponin named ginsenoside Rh_1 with the structure established as 6-*O*-β-D-glucopyranoside of 20 (*S*)-protopanaxatriol was isolated from ginseng root (Yahara et al. 1979). A ginsenoside Rg_2 was isolated from ginseng root (Kaku and Kawashima 1980). Two new dammarane saponins, named ginsenoside Ra_1 and ginsenoside Ra_2, were isolated from ginseng roots and their structures established as 20(*S*)-protopanaxadiol3-*O*-β-D-glucopyranosyl-(1→2)-β-D-glucopyranoside-20-*O*-β-D-xylopyranosyl (1→4)-α-L-arabinopyranosyl (1→6)-β-D-glucopyranoside and 20 (*S*)-protopanaxadiol 3-*O*-β-D-glucopyranosyl (1→2)-β-D-glucopyranoside-20-*O*-β-D-xylopyranosyl (1→2)-α-L-arabinofuranosyl (1→6)-β-D-glucopyranoside, respectively (Besso et al. 1982). The presence of ginsenoside Ra in ginseng root was demonstrated and shown to be a mixture of more than two saponins (Koizumi et al. 1982). Among them, ginsenoside Ra_1 was isolated and its structure was as 20 (*S*)-protopanaxadiol 3-*O*-β-D-glucopyranosyl (1→2)-β-D-glucopyranosido-20-*O*-β-D-xylopyranosyl (1→4)-α-L-arabinopyranosyl (1→6)-β-D-glucopyranoside. Besides compound K (8), three prosapogenins – 20(*S*)-protopanaxadiol3-O-β-D-glucopyranosido-20-O-β-D-glucopyranoside (7); 20 (*S*)-protopanaxadiol 3-*O*-β-D-glucopyranosido-20-*O*-β-D-xylopyranosyl (1→4)-α-L-arabinopyranosyl (1→6)-β-D-glucopyranoside (9); and 20 (*S*)-protopanaxadiol 20-*O*-β-D-xylopyranosyl (1→4)-α-L-arabinopyranosyl (1→6)-β-D-glucopyranoside (10) – were obtained in the course of enzymatic hydrolysis of ginsenoside Ra_1. Further, 20 (*S*)-protopanaxadiol 3-*O*-β-D-glucopyranosido-20-*O*-α-L-arabinopyranosyl (1→6)-β-D-glucopyranoside (6), 7 and 8 were obtained by enzymatic hydrolysis of ginsenoside Rb_2. From red ginseng, all of the known saponins of white ginseng, namely, ginsenosides R0 (chikusetsusaponin V), G-Ra1, G Ra2, Rb1, Rb2, Rb3, Rc, Rd, Re, Rf, Rg1, Rg2, Rg3, Rh1, 20-gluco-ginsenoside Rh2 were isolated in yields similar to those obtained from white ginseng (Kasai et al. 1983). Two additional minor saponins, notoginsenoside R_1 (the saponin of *Panax notoginseng* roots) and quinquenoside R_1 (the saponin of *P. quinquefolium* roots), were also isolated and identified. Besides these known saponins, two new minor saponins named ginsenosides Rs_1 and Rs_2 were also isolated and established to be monoacetates at the 6-hydroxyl group of the terminal glucosyl moiety of the sophorosyl unit of ginsenosides Rb_2 and Rc, respectively. A new dammarane saponin named ginsenoside Ra_3 was isolated from both white and red Ginseng with yields of 0.005 %, and its structure was established to be (20*S*)-protopanaxadiol 3-*O*-(β-D-glucopyranosyl (1→2)-β-D-glucopyranosido)-20-*O*-β-D-xylopyranosyl (1→3)-β-D-glucopyranosyl (1→6)-β-D-glucopyranoside (Matsuura et al. 1984b). Further, notoginsenoside R_4, previously isolated from sanchi ginseng *Panax notoginseng* roots, was also isolated from red ginseng with a yield of 0.002 %. Four new malonylated dammarane-type triterpene oligosaccharides named malonyl-ginsenosides Rb1, Rb2, Rc and Rd were isolated from ginseng roots (Kitagawa et al. 1983).

Ten saponins were isolated from Chinese red ginseng: 20(*R*)-ginsenoside Rh_1, ginsenoside Rg_3, 20(*R*) ginsenoside Rg_2, 20(*R*)protopanaxatriol, ginsenoside Rg_1, ginsenoside Re, ginsenoside Rd, ginsenoside Rc, ginsenoside Rb_2 and ginsenoside Rb_1 (Xu et al. 1986). Fresh ginseng root was found to contain malonyl-ginsenosides Rb_1, Rb_2, Rc and Rd and ginsenosides Rd, Re, Rf, Rg_1 and Rg_2, palmitic acid, linoleic acid, panaxynol,panaxydol,1-*O*-β-D-galactopyranosyl-D-glycerol and steryl glucoside fatty acid ester (Kitagawa et al. 1987). Red ginseng roots were found to contain ginsenoside Rg_2, 20(*R*)-ginsenoside Rg_2; 20(s)-ginsenoside Rg_8; ginsenoside Rg_3; ginsenoside Rh_1; 20(*R*)-ginsenoside Rh_1; ginsenoside Rh2; ginsenosides Rd, Re, Rf, Rg_1, Ro, Rb_1, Rb_2 and Rc; palmitic acid; linoleic acid; panaxynol; panaxydol; heptadec-1-ene-4,6-diyne-3,9-diol; panaxytriol and -*O*-β-D-galactopyranosyl-D-glycerol; and steryl glucoside fatty acid ester. White ginseng root was found to contain ginsenosides Ro, RB_1, Rb_2, Rc, Rd, Re, Rf, Rg_1 and Rg_2; malonyl-ginsenosides Rb_1, Rb_2, Rc and Rd; and palmitic acid, linoleic acid,

panaxynol, panaxydol, steryl glucoside and fatty acid ester (lesser amounts).

Neutral saponins ginsenosides Rb_1, Rb_2, Rc, Rd, Re, Rf and RG_1 and acidic manolates of the dammarane saponins malonyl-ginsenosides Rb_1, Rb_2 and Rd and ginsenoside Ro which was identical with chikusetsusaponin V were found in ginseng rhizomes and roots (Yamaguchi et al. 1988). Four malonylated dammarane-type triterpene oligoglycosides, named malonyl-ginsenosides Rb_1, Rb_2, Rc and Rd, were isolated from the water-soluble portion of the dried ginseng root (Kitagawa et al. 1989). Their structures were elucidated respectively as 3-*O*-[6-*O*-malonyl-β-D-glucopyranosyl(1→2)-β-D-glucopyranosyl]-20-*O*-[β-D-glucopyranosyl(1→6)-β-D-glucopyranosyl]-20(*S*)-protopanaxadiol;3-*O*-[6-*O*-malonyl-β-D-glucopyranosyl(1→2)-β-D-glucopyranosyl]-20-*O*-[α-L-arabinopyranosyl(1→6)-β-D-glucopyranosyl]-20(*S*)-protopanaxadiol;3-*O*-[6-*O*-malonyl-β-D-glucopyranosyl(1→2)-β-D-glucopyranosyl]-20-*O*-[α-L-arabinofuranosyl(1→6)-β-D-glucopyranosyl]-20(*S*)-protopanaxadiol;and3-*O*-[6-*O*-malonyl-β -D-glucopyranosyl(1→2)-β-D-glucopyranosyl]-20-*O*-[β-D-glucopyranosyl]-20(*S*)-protopanaxadiol.

More than 25 dammarane-type saponins had been identified as the characteristic principles of white and red ginseng (Shibata 2001). White ginseng was found to contain Rb_1, Rb_2, Rc, Rd, Rg_3 20(S) protopanaxadiol-type ginsenosides; Re, Rf, Rg_1, Rg2, Rh_1 20(S) protopanaxatriol-type ginsenosides; and Ro oleanane-type ginsenoside. Red ginseng was found to contain 20(S) protopanaxadiol-type ginsenosides: Rb_1, Rb_2, Rc, Rd, Rg_3 (20R), Rg_3 (20S), Rh_2; 20(S) protopanaxatriol-type ginsenosides: Re, Rf, Rg_1, Rg_2 (20R), Rg_2 (20S), Rh_1 (20R), Rh_1 (20S); and oleanane-type ginsenoside Ro. Three new ginsenosides named ginsenosides Rh_{10}, Rg_{11} and 12-*O*-glucoginsenoside Rh_4 were isolated from heat-processed ginseng roots, and their respective structures were determined to be 3β,12β,25-trihydroxydammar-20E(22)-ene-3-*O*-β-D-glucopyranoside; 3β,12β,23-trihydroxy-24,25-epoxydammar-20E(22)-ene-3-*O*-β-D-glucopyranosyl(1→2)-β-D-glucopyranoside; and 3β,6β,12β-trihydroxydammar-20*E*(22),24-diene-6-*O*-β-D-glucopyranosyl-12-*O*-β-D-glucopyranoside (Cho et al. 2013a).

Four chemical constituents were isolated fresh ginseng root cultivated in China, and three of them were elucidated as malonyl-ginsenosides Rb1, Rb2 and Rd (Wang et al. 1993). Two new minor dammarane saponins named koryoginsenosides R_1 and R_2 were isolated from ginseng roots, along with 14 known saponins (Kim et al. 1995a). The structures of the new saponins were elucidated as 6-*O*-[*trans* butenoyl-(1→6)-β-D-glucopyranosyl]-20-*O*-β-D- glucopyranosyl dammar-24-en-3β,6α,12 β,20(*S*)-tetrol and 3-*O*-[β-D-glucopyranosyl-(1→2)-β-D-glucopyranosyl]-20-*O*-[β-D- glucopyranosyl-(1→6)-β-D-glucopyranosyl] dammar-22-en-3β,12 β, 20(*S*),- 25-tetrol, respectively. A genuine dammarane glycoside, named ginsenoside Rg_5, was isolated from the methanol extract of Korean red ginseng (Kim et al. 1996). The chemical structure of ginsenoside Rg_5 was determined as 3-*O*-[β-D-glucopyranosyl (1→2)-β-D-glucopyranosyl] dammar-20(22),24-diene-3β,12β-diol. A genuine glycoside, named ginsenoside Rh_4, was isolated from Korean red ginseng, and its chemical structure was established to be 6-*O*-β-D-glucopyranosyldammar-20(22),24-diene-3β,6α,12β-triol (Baek et al. 1996). A genuine dammarane glycoside, (20*E*)-ginsenoside F 4 was isolated from Korean red ginseng (Ryu et al. 1996). A new dammarane glycoside, named ginsenoside Rg_6, was isolated from the Korean red ginseng (Ryu et al. 1997). Its chemical structure was established to be 3β,6α, 12β-trihydroxydammar-20 (21), 24-diene-6-*O*-α-L-rhamnopyranosyl-(1→2)-β-D-glucopyranoside. Four new dammarane glycosides named ginsenosides Rg_5, Rh_4, Rs_3 and Rf_2 were isolated from Korean red ginseng, and their chemical structures were elucidated as 3-*O*-[β-D-glucopyranosyl (1→2)-β-D-glucopyranosyl]dammar-20(22), 24-diene-3β,12β-diol (ginsenoside Rg_5), 6-*O*-β-D-glucopyranosyl-dammar-20(22), 24-diene-3β, 6aα,12β-triol(ginsenosideRh_4),3-*O*-[6″-*O*-acetyl-β-D-glucopyranosyl(1→2)-β-D-glucopyranosyl] 20(S)-protopanax adiol(ginsenoside Rs_3) and 6-*O*-[α-L-rhamnopyranosyl(1→2)-β-D-

glucopyranosyl]dammarane-3β,6α,12β,20(*R*), 25-pentol (ginsenoside Rf_2) (Park et al. 1998a). Ginsenoside Rs_4 (an acetylated analogue of ginsenoside Rg_5), a new ginseng saponin, was isolated from *Panax ginseng* (Kim et al. 1999e). The ginsenoside-β-glucosidase that hydrolyses the β-(1→2)-glucoside of the ginsenoside Rg_3 sugar moiety to ginsenoside Rh_2 was isolated from ginseng root (Zhang et al. 2001). It had a molecular weight of 59 kDa. Ca^{2+} ion had a positive effect on ginsenoside-β-glucosidase, while Cu^{2+} had a negative effect on it. Rg_3 was found to be a 20(*S*)-ginsenoside Rh_2, i.e. a 3-*O*-(β-D-glucopyranosyl)-dammar-24-en-3β,12β,20(*S*)-triol. Polyacetylene-ginsenoside Ro, a new oleanolic acid-derived saponin, was isolated along with the known ginsenosides Ro methyl ester, ginsenoside Rf, ginsenoside Rg_1, ginsenoside Rg_2 and ginger glycolipid B from ginseng roots (Zhang et al. 2002). Four new acetylated ginsenosides named ginsenoside Rs_4, Rs_5, Rs_6 and Rs_7 were isolated from processed ginseng (SG, sun ginseng) (Park et al. 2002a). Their structures were determined to be 3β,12β-dihydroxydammar-20(22),24-diene-3-*O*-β-D-glucopyranosyl(1→2)-P-D-6″-*O*-acetyl-glucopyranoside; 3β,12β-dihydroxydammar-20(21), 24-diene-3-*O*-β-D-glucopyranosyl(1→2)-β-D-6″-*O*-acetylglucopyranoside; 3β, 6α,12p-trihydro-xydammar-20(22),24-diene-6-*O*-β-D-6′-*O*-acetylglucopyranoside; and 3β,6α, 12β-trihydroxydam-mar-20(21),24-diene-6-*O*-β-D-6′-*O*-acetylglucopyranoside, respectively. Fourteen major ginsenosides Rg_1, Re, Rf, Rh_1, Rg_2, Rb_1, Rc, Rb_2, Rb_3, Rd, Rg_3, Rk_1, Rg_5 and Rh_2 were determined as marker compounds of Korean red ginseng by reverse-phase HPLC-ELSD (Kim et al. 2007c).

Artificial triterpenoids, (20*R*)-20,25-epoxy-dammaran-2-en-6α,12β-diol;(20*R*)-20,25-epoxy-3-methyl-28-nordammaran-2-en-6α,12β-diol and isodehydroprotopanaxatriol, were isolated from an acidic hydrolysate of *Panax ginseng*, along with three known triterpenes: (20*R*)-panaxadiol, (20*R*)-panaxatriol and oleanolic acid (Wei et al. 2009). Two malonyl-ginsenosides, malonyl-ginsenoside Rc and malonyl-ginsenoside Rb_2, were isolated from the fresh ginseng root, and their structures were elucidated as 3-*O*-[6-*O*-malonyl-β-D-glucopyranosyl(1→2)-β-D-glucopyranosyl]-20-*O*-[α-L-arabinofuranosyl(1→6)-β-D-glucopyranosyl]-20(S)-protopanaxadiol and 3-*O*-[6-*O*-malonyl-β-D-glucopyranosyl-(1→2) β-D-glucopyranosyl]-20-*O*-[α-L-arabino-pyranosyl(1→6)-β-D-glucopyranosyl]-20(*S*)-protopanaxadiol, respectively (Sun et al. 2005). Ginsenoside Rh_1 and compound K were purified from fermented ginseng (Kim et al. 2008a). Hydrolysis of ginsenoside Rb_1, Rb_2 and Rc with 50 % aqueous acetic acid afforded 20R-prosapogenin, 20S-prosapogenin and delta 20-prosapogenin. Ginsenosides found in the roots included Rb_1, Rb_2, Rc, Rd, Re and RG_1 (Sugimoto et al. 2009). A new panaxadiol ginsenoside was isolated from ginseng acid hydrolysate, and its structure was elucidated as dammar-(*E*)-20(22)-ene-3β,12β,25-triol (Li et al. 2009). A new dammarane-glycoside, ginsenoside Rz_1 (1), was isolated from heat-treated *P. ginseng* with ginsenosides Rk_1 and Rg_5 (Lee et al. 2009e). The structure of 1 was established to be (Z)-12β-hydroxydammara-20(22),24-dien-3β-yl *O*-β-D-glucopyranosyl-(1→2)-β-D-glucopyranoside. The ginsenosides Rz_1, Rk_1 and Rg_5 were present in the ratios of 1:2:6, respectively.

A new saponin, malonyl-ginsenoside Ra_3, with the structure (20*S*)-protopanaxadiol-3-*O*-(6-*O*-malonyl-β-D-glucopyranosyl(1→2)-β-D-glucopyranoside-20-*O*-β-D-xylopyranosyl (1→3)-β-D-glucopyranosyl(1→6)-β-D-glucopyranoside was isolated from the fresh ginseng root, along with four known ginsenosides, namely, malonyl-ginsenoside Rb_1, malonyl-ginsenoside Rb_2, malonyl-ginsenoside Rc and malonyl-ginsenoside Rd (Ruan et al. 2010). Six new natural protopanaxatriol (PPT)-type ginsenosides, ginsenosides Re_1–Re_6, along with ten known PPT-type ginsenosides, were isolated from ginseng roots (Zhu et al. 2011b). Six new protopanaxadiol-type ginsenosides, named ginsenosides Ra_4–Ra_9, along with 14 known dammarane-type triterpene saponins, were isolated from ginseng root (Zhu et al. 2011a). The structures of the new compounds were determined as (20*S*)- 3-*O*-{β-D-6-*O*-[(*E*)-but-2-enoyl] glucopyranosyl-(1→2)-β-D-glucopyranosyl}-20-*O*-[β-D-xylopyranosyl-(1→4)-α-L-arabino-

pyranosyl-(1→6)-β-D-glucopyranosyl] protopanaxadiol; (20*S*)-3-*O*-[β-D-6-*O*-acetylglucopyranosyl-(1→2)-β-D-glucopyranosyl]-20-*O*-[β-D-xylopyranosyl-(1→4)-α-L-arabinopyranosyl-(1→6)-β-D-glucopyranosyl]protopanaxadiol; (20*S*)-3-*O*-{β-D-6-*O*-[(*E*)-but-2-enoyl]glucopyranosyl-(1→2)-β-D-glucopyranosyl}-20-*O*-[β-D-glucopyranosyl-(1→6)-β-D-glucopyranosyl]protopanaxadiol; (20*S*)-3-*O*-{β-D-6-*O*-[(*E*)-but-2-enoyl] glucopyranosyl-(1→2)-β-D-glucopyranosyl}-20-*O*-[α-L-arabinopyranosyl-(1→6)-β-D-glucopyranosyl]protopanaxadiol; (20*S*)-3-*O*-{β-D-4-*O*-[(*E*)-but-2-enoyl]glucopyranosyl-(1→2)-β-D-glucopyranosyl}-20-*O*-[α-L-arabinofuranosyl-(1→6)-β-D-glucopyranosyl]protopanaxadiol; and (20*S*)-3-*O*-{β-D-6-*O*-[(*E*)-but-2-enoyl] glucopyranosyl-(1→2)-β-D-glucopyranosyl}-20-*O*-[α-L-arabinofuranosyl-(1→6)-β-D-glucopyranosyl]protopanaxadiol, respectively. One new dammarane triterpene saponin named ginsenjilinol was isolated from ginseng roots and rhizomes together with two known saponins ginsenoside Rf and ginsenoside Re_5 (panajaponol A) (Wang et al. 2013a). The chemical structure of the new saponin was elucidated as 3β,12β,20*S*,26-tetrahydroxydammar-24E-en-6α-*O*-β-D-glucopyranosyl-(1→2)-*O*-β-D-glucopyranoside. A new ginsenoside, 20(*R*)-ginsenoside Rf, was purified from red ginseng extract (Lee et al. 2013g). Park et al. (2013a) using an ultra-performance liquid chromatography simultaneously determined 30 ginsenosides in ginseng roots: ginsenosides Ro, Rb_1, Rb_2, Rc, Rd, Re, Rf, Rg_1, 20(*S*)-Rg_2, 20(*R*)-Rg_2, 20(*S*)-Rg_3, 20(*R*)-Rg_3, 20(*S*)-Rh_1, 20(*S*)-Rh2, 20(*R*)-Rh_2, F_1, F_2, F4, Ra_1, Rg_6, Rh_4, Rk_3, Rg_5, Rk_1, Rb_3, Rk_2, Rh_3, compound Y and compound K and notoginsenoside R_1. Three derivatives were synthesised from 25-hydroxyprotopanaxadiol from ginseng root, namely, (20R)-12β-*O*-(l-chloracetyl)-dammarane-3β, 20, 25-triol; (20R)-3β-*O*-(l-alanyl)-dammarane-12β, 20, 25-triol; and (20R)-3β- *O*-(Boc-l-arginyl)-dammarane-12β, 20, 25-triol (Xia et al. 2014).

Nineteen ginsenosides (Rg_1, Re, Rf, Rb_1, Rc, Rb_2, Rd, F_4, Rg_6, Rk_3, Rh_4, 20(*S*)-, 20(*R*)-Rg_3, 20(*S*)-, 20(*R*)-Rs_3, Rk_1, Rg_5, Rs_4 and Rs_5) were identified and quantified in black ginseng (Korean white ginseng that was subjected to nine cycles of steam treatment) (Sun et al. 2009). Nineteen ginsenosides (Rg_1, Re, Rf, Rb_1, Rc, Rb_2, Rd, F_4, Rg_6, Rk_3, Rh_4, 20(*S*)-, 20(*R*)-Rg_3, 20(*S*)-, 20(*R*)-Rs_3, Rk_1, Rg_5, Rs_4 and Rs_5) were identified and quantified in black ginseng (Korean white ginseng that was subjected to nine cycles of steam treatment) (Sun et al. 2009). Ultra-high pressure (UHP) (600 MPa for 5–15 minute) extracted ginseng showed relatively higher extraction yield (312.2–387.1 mg) and amounts of crude saponins (19.3–32.6 mg/g ginseng) than control ginseng (189.9 and 17.5 mg/g ginseng, respectively) (Shin et al. 2010). Amounts of measured total ginsenosides (Rb1, Rb2, Rc, Rd, Re and Rg1) increased with UHP processing, but pressure level and pressing time did not proportionally influence the ginsenosides content. The levels of ginsenosides Rg_1 and Re in hydroponic-cultured ginseng roots (HGR) decreased with increasing heating temperature. Ginsenosides F_2, F_4, Rk_3, Rh_4, Rg_3 (S form), Rg_3 (R form), Rk_1 and Rg_5, which were absent in the raw ginseng, were formed after heat treatment (Hwang et al. 2014). The levels of ginsenosides Rg1, Re, Rf and Rb1 in hydroponic ginseng leaves (HGL) decreased with increasing heating temperature. Conversely, ginsenosides Rk_3, Rh_4, Rg_3 (R form), Rk_1 and Rg_5 increased with increasing heating temperature. In addition, ginsenoside contents of heated HGL were slightly higher than those of HGR. The highest extraction yield was 14.39 % at 130 °C, whereas the lowest value was 10.30 % at 150 °C. After heating, polyphenol contents of HGR and HGL increased from 0.43 mg GAE eq./g and 0.74 mg GAE eq./g to 6.16 mg GAE eq./g and 2.86 mg GAE eq./g, respectively.

Samukawa et al. (1995a) found that in *P. ginseng* cultivated in Nagano, Japan, the ratio (total ginsenosides content/total dry root weight) increases annually for 3 years, and it decreased at the fourth year and increased again at the fifth and the sixth years. Concerning the distribution of ginsenosides in the parts of ginseng plant, ginsenosides were found at the highest level in a lateral root followed by rhizome > root hair > main root. They were also more abundantly distributed at periderm than at phloem or at xylem of a main

root. The contents of panaxadiol and panaxatriol saponins gradually increased with the growth year, whereas an oleanane saponin, ginsenoside Ro, markedly increased at the sixth year to 15-fold. The following saponins in ginseng root were simultaneously analysed by high-performance liquid chromatography (HPLC): ginsenoside Ro, ginsenoside Rb_1, ginsenoside Rb_2, ginsenoside Rb3, ginsenoside Rc, ginsenoside Rd, ginsenoside Re, ginsenoside Rf, ginsenoside Rg_1, ginsenoside Rs_1, 20(*S*)-ginsenoside Rg_2, 20(*S*)-ginsenoside Rg3, 20(S)-ginsenoside Rh_1, 20(*R*)-ginsenoside Rg2, 20(*R*)-ginsenoside Rg3, 20(*R*)-ginsenoside Rh_1 and quinquenoside R_1 (Samukawa et al. 1995b).

Hairy root culture of ginseng transformed with *Agrobacterium rhizogenes* synthesised the same saponins, ginsenosides, as those of the native root, up to about 2.4 times in the quantity and up to two-fold in comparison with that of the ordinary cultured roots, on a dry weight basis (Yoshikawa and Furuya 1987). The amount of the Rb group was calculated as the total of ginsenosides Ra and Rd, having protopanaxadiol as the sapogenin, and the Rg group was the total of ginsenosides Re, Rf, Rg_l, Rg_2 and Rh, having protopanaxatriol as sapogenin. Agropine and mannopine synthesised in the ginseng hairy roots were also extracted. Both of the elicitors tested, yeast extract and methyl jasmonate, significantly improved saponin production in ginseng cell suspensions (Lu et al. 2001). The highest additive level of the seven ginsenosides tested was 2.07 % (dry weight basis), which was 28-fold higher than that in the control. When yeast extract was used as the elicitor, Rg_1, Rf, Rb_1, Rc and Rd contributed to the increase in total saponin content, while the change in Re was insignificant. When methyl jasmonate was used, the increase in saponin content was mainly due to a dramatic increase in the level of Rb_1, followed by Rc. The increases in Rg_1, Re and Rf were much less significant; Rd was undetectable. The maximum content of ginsenosides was found in the suspension culture cultivated in the bioreactor (4.34 % dry mass); however, the saponin content was limited to two major ginsenosides, Rb_1 and Rg_1 (Langhansova et al. 2005). The production of ginsenosides in adventitious roots was lower (1.45 or 1.72 % dry mass); nevertheless, the full range of ginsenosides (Rg_1, Re, Rf, Rb1, Rb2, Rc and Rd) was detected. A combination of steaming and *Aspergillus niger* isolated from soil biotransformed black ginseng Rg_3(S, R) into 20(S)-protopanaxadiol (PPD(S)) with 100 % conversion (Liu et al. 2010b). The biotransformation pathways were Rg_3(S)→Rh_2(S)→PPD(S) and Rg_3(R)→Rh_2(R)→20(R)-protopanaxadiol (PPD(R)), respectively. In addition, 12 ginsenosides including three pairs of epimers, namely, Rg3(S), Rg_3(R), Rh_2(S), Rh_2(R), PPD(S) and PPD(R), were simultaneously determined.

The yield of methanolic extract of fresh ginseng roots harvested in winter was found to be more than twofold greater than from roots collected in summer; this notable increase was mainly due to the large increase of sucrose in roots in winter (Kim et al. 1981). In contrast, active dammarane saponins in the roots increased in summer indicating that roots should be harvested in summer for the production of high-quality ginseng extracts. Cultivation year and storage period affected total ginsenosides in fresh ginseng, while cultivation locations and cultivation year affected phenolics in fresh ginseng (Chung et al. 2012). Processed ginsengs especially red ginseng contained larger amounts of ginsenosides and phenolics. Total ginsenosides decreased to 20–80 % in all ginsengs (fresh, white, taegeuk and red ginseng) after 1 year storage. The total content of 30 phenolics increased to 30–100 % only in processed ginsengs after 1-year storage.

Incubation of ginseng sapogenins 20(S)-protopanaxadiol and 20(S)-protopanaxatriol with microsomes from rat liver resulted in the formation of their 20, 24-epoxides as major metabolites, i.e. 20(S)-protopanaxadiol oxide I (24R epimer) and 20(S)-protopanaxadiol oxide II (24S-epimer) and 20(S)-protopanaxatriol (24S-epimer) and 20(S)-protopanaxatriol (24 R-epimer) (Kasai et al. 2000).

Polyacetylene Compounds

Panaxydol, a new polyacetylenic epoxide with the structure 9,10-epoxy-3-hydroxyheptadeca-1-

en-4,6-diyne (Poplawski et al. 1980); heptadeca-1-en-4,6-diyn-3.9-diol (Dabrowski et al. 1980); heptadeca-1-ene-4,6-diyne-3,9,10-triol (Sang et al. 1983); and heptadeca-1,8-dien-4,6-diyn-3,10-diol (Shim et al. 1987), was isolated from ginseng roots. Two new polyacetylenes, viz. heptadeca-3-oxo-4,6-diyne-9,10-diol and its dihydro derivative (Fujimoto and Satoh 1987), and new chlorine-containing polyacetylene, chloropanaxydiol and panaxydol were isolated from ginseng callus (Fujimoto and Satoh 1988). From ginseng roots cytotoxic polyacetylene compounds: panaxyne epoxide with the structure tetradeca-13-ene-1,3-diyne-6,7-epoxide (Kim et al. 1989a); and 10-acetyl panaxytriol with the structure heptadeca-1-ene-4,6-diyne-3,9-diol-10-acetate (Kim et al. 1989b) were isolated. Two new polyines, 3-acetyloxy-9,10-epoxy-heptadec-1-en-4,6-diyne (acetylpanaxydol) and 10-chloro-3,9-dihydroxyheptadec-1-en-4,6-diyne (panaxydol chlorohydrin), were isolated from the roots (Ahn et al. 1989). The heptadeca-1-ene-4,6-diyne-3,9,10-triol (panaxytriol) contents of red ginseng and white ginseng were determined as 0.38 and 0.25 mg/g, respectively (Matsunaga et al. 1989a). Three polyacetylene compounds, panaxynol, panaxydol and panaxytriol, were found in *P. ginseng* (Matsunaga et al. 1990). Three new acetylated polyacetylenes named ginsenoynes F, G and H were isolated from the hexane extract of ginseng roots (Hirakura et al. 1991b). Five new polyacetylenes named ginsenoynes A, B, C, D and E were isolated from the hexane extract of ginseng root (Hirakura et al. 1991a). Three new acetylenic compounds named ginsenoynes I–K were isolated from a hexane extract of ginseng roots (Hirakura et al. 1992). The following polyacetylenic compounds were isolated from ginseng roots: ginsenoyne A, panaxyne epoxide, panaxydol and panaxynol (Hirakura et al. 1994). Polyacetylene compounds identified as panaxynol, panaxydol, panaxydiol and panaxytriol were isolated from ginseng hairy roots (Kwon et al. 1997). The absolute stereostructures of panaxytriol and panaxydol, two polyacetylenic constituents red ginseng roots, were determined to be (3*R*,9*R*,10*R*)-heptadec-1-ene-4,6-diyne-3,9,10-triol and (3*R*,9*R*,10*S*)-9,10-epoxy-heptadec-1-ene-4,6-diyn-3-ol, respectively (Kobayashi et al. 1997). Panaxytriol was presumed to be formed from panaxydol via a regioselective hydrolysis of the epoxy moiety in panaxydol.

Sixteen acetylenic compounds were isolated from ginseng roots: panaxynol; panaxydol; panaxydol chlorohydrins; panaxytriol; panaxyne epoxide; ginsenoynes A, C, D, E, H, I, J and K; panaxynol linoleate; panaxydol linoleate; and ginsenoyne A linoleate (Hirakura et al. 2000). Four possible stereoisomers of (9,10)-epoxyheptadecan-4,6-diyn-3-one were synthesised, and the absolute configuration of the naturally occurring (9*R*,10*S*)-epoxyheptadecan-4,6-diyn-3-one, a diacylglycerol acyltransferase inhibitor from ginseng, was elucidated (Oh et al. 2004b). Polyacetylenic compounds, (9*R*,*10*S)-epoxyheptadecan-4,6-diyn-3-one and 1-methoxy-(9*R*,10*S*)-epoxyheptadecan-4,6-diyn-3-one (Lee et al. 2004d) and (9*R*,*10S*)-epoxy-16-heptadecene-4,6-diyne-3-one (Rho et al. 2005) were obtained from the petroleum ether extract of ginseng. Using a new HPLC method, white ginseng and red ginseng were found to contain three polyacetylenes (panaxynol, panaxydol and 1,8-heptadecadiene-4,6-diyne-3,10-diol), 0.02–0.073 % in white ginseng and 0.019–0.055 % in red ginseng, and six ginsenosides (RB_1, Rb_2, Rc, Rd, Re and Rg_1), 1.072–3.029 % in white ginseng and 1.588–2.811 % in red ginseng (Washida and Kitanaka 2003). Ginseng root samples were found to contain polyacetylenes (panaxydol and panaxynol), 1.93–2.72 mg/g, and saponins (ginsenosides Rg_1, Re, Rf, Rg_2, Rb_1, Rc, Rb_2, Rb_3 and Rd), 12.67–18.64 mg/g, and no flavonoid (panasenoside) (Qian et al. 2009). Seven polyacetylenes – panaxynol, ginsenoyne-A, panaxydol, 10-methoxy heptadeca-1-ene-4, 6-dyne-3, 9-diol, (3*R*, 9R, 10*R*)-panaxytriol, panaxyne and ginsenoyne-C – were isolated from the roots of cultivated wild ginseng (Jangnoisam) (Yang et al. 2008). A polyacetylenic compound, (9*R*,10*S*)-epoxyheptadecan-4,6-diyn-3-one (EHD), was isolated from ginseng root extract (Choi et al. 2008). Panaxfuraynes A and B and two new tetrahydrofuranic polyacetylene glycosides were isolated from ginseng roots (Lee et al. 2009d). Two

new polyacetylenes, 1-hydroxydihydropanaxacol and 17-hydroxypanaxacol, were isolated from *Panax ginseng* hairy root culture, along with dihydropanaxacol, panaxacol and ginsenoyne D (Fukuyama et al. 2012).

Other Phytochemicals

Horhanmer et al. (1961) isolated from ginseng roots a pentacyclic, oleanane-type (5–8) triterpene compound named oleanolic acid (5–9). New glucosides 1 and 2 were isolated from a non-saponin fraction of a water extract of red ginseng (steamed ginseng root) (Matsuura et al. 1984a). One was identified as 2-oxopropyl a-D-glucopyranoside (acetol α-D-glucoside) which showed negligibly weak mutagenicity in *Salmonella typhimurium* TA100 with and without S9 and no mutagenicity in the strains TA98 and Ta1537. Glucoside 2 was an unstable C-2-epimeric mixture, which was readily decomposed to give maltol and glucose, suggesting it to be an intermediate in the formation of maltol from maltose during the steaming process.

The unknown ninhydrin-positive substances (UK-I, UK-II, UK-III) were detected in ginseng water extract (Matsuura et al. 1994). UK-II was isolated and identified as maltulosyl arginine (Arg-Fru0Glc), and UK-III was identified as Arg-Fru. Korean red ginseng contained more Maltulosyl arginine than white ginseng. Maltulosyl arginine was found to be produced by Maillard reaction of maltose with arginine during the heating process in the preparation of red ginseng. Maltulosyl arginine was found to inhibit maltase activity. Five ninhydrin-positive compounds were isolated from red ginseng water extract including arginine and a new compound determined as 1′-Nα-arginine-1′-deoxy-4′-*O*-(α-D-glucopyranosyl)-D-fructose (argininyl-fructosyl-glucose) (Zheng et al. 1998). Two Amadori compounds, arginyl-fructose and arginyl-fructosyl-glucose, were found in Korean red ginseng extracts and rat plasma (Joo et al. 2008).

Five new compounds (three esters and two glycosides) elucidated as digitoxigenin stearate, digitoxigenin palmitate, digitoxigenin myristate, 3-epidigitoxigenin β-D- gentiobioside and digitoxigenin β-D-sophoroside and seven previously reported compounds were isolated as biotransformation products of digitoxigenin by ginseng hairy root cultures (Kawaguchi et al. 1990). Nine compounds, including a new compound (digitoxigenin β-D-glucoside malonyl ester), were isolated as biotransformation products of digitoxigenin by cell suspension cultures of *Panax ginseng* (Pg-3 cell line) (Kawaguchi et al. 1996). On administration of 18 β-glycyrrhetinic acid to hairy root cultures of *Panax ginseng*, three new biotransformation products – 30-*O*-[β-D-glucopyranosyl-(1→2)-β-D- glucopyranosyl]18 β-glycyrrhetinic acid, 30-*O*-(6- *O*-malonyl-β-D-glucopyranosyl)18 β-glycyrrhetinic acid and 3-*O*-[6-*O*- malonyl-β-D-glucopyranosyl-(1→2)-β-D-glucopyranosyl]18 β-glycyrrhetinic acid – were isolated together with three known compounds (Asada et al. 1993). Upon addition of hydroquinone to ginseng hairy root culture, arbutin was obtained as biotransformed product in 24 hours, the bioconversion rate was 89.0 %, and the content of arbutin in dry root was 13.0 % (Zhao et al. 2001).

Ginseng root culture was able to convert 3,5-dimethoxyphenol (taxicatigenin) into its glucoside (taxicatin), primeveroside and gentiobioside; methyl salicylate into its glucoside and gentiobioside; *p*-hydroxyacetophenone into its glucoside (picein); and coniferyl alcohol into dihydroconiferin [3-(3-methoxy-4-*O*-β-D-glucopyranosylphenyl)propan-1-ol] (Ushiyama and Furuya 1989). Root cultures of *P. ginseng* were able to convert (*RS*)-2-phenylpropionic acid into (*RS*)-2-phenylpropionyl β-D-glucopyranoside, (2*RS*)-2-*O*-(2-phenylpropionyl)-D-glucose, (2*S*)-2-phenylpropionyl 6-*O*-β-D-xylopyranosyl-β-D-glucopyranoside and a *myo*-inositol ester of (*R*)-2-phenylpropionic acid (Furuya et al. 1989). Ginseng root culture was able to convert aromatic carboxylic acids into glucose and/or sophorose substituted conjugates (Ushiyama et al. 1989). 2-(4-hydroxyphenyl) propionic acid was converted into its *R* and *S* glucosyl esters and glucosides, its ethyl ester into a glucoside and a small amount of a glucosyl ester, (4-hydroxyphenyl) acetic acid into its glucoside, tropic acid into its glucose esters and glucosides and 2-(3-benzoylphenyl) propionic acid and 2-[2-

(6-methoxy)-naphthyl] propionic acid into their glucosyl and sophorosyl esters.

Panax ginseng root cultures biotransformed umbelliferone into its 7-*O*-β-D-glucopyranoside; 7-*O*-β-D-glucopyranosyl (1→6) β-D-glucopyranoside, 7-*O*-β-D-xylopyranosyl (1→6) β-D-glucopyranoside; and 7-*O*-α-l-rhamnopyranosyl (1→2) β-D-glucopyranoside (Li et al. 2002). The glycosylation was catalysed by glycosyltransferase rather than glycosidase. Also, *Panax ginseng* root and cell cultures were shown to biotransform paeonol into its 2-*O*-β-D-glucopyranoside (Li et al. 2005).

P. ginseng root cultures were also able to biotransform paeonol into 2-*O*-β-D-xylopyranoside, 2-*O*-β-D-glucopyranosyl(1→6)-β-D-glucopyranoside and 2-*O*-β-D-xylopyranosyl (1→6)-β-D-glucopyranoside, and its demethylated derivate, 2′,4′-dihydroxyacetophenone. *p*-Hydroxybenzoic acid and *m*-hydroxybenzoic acid were converted into their corresponding glycosides and glycosyl esters, while no metabolite of *o*-hydroxybenzoic acid was detected in ginseng root cultures (Chen et al. 2008). A new compound, *m*-hydroxybenzoic acid β-D-xylopyranosyl (1→6)-β-D-glucopyranosyl ester, was identified as a biotransformation product of *m*-hydroxybenzoic acid.

Eighty-two components were detected in non-fumigated and sulfur-fumigated white ginseng samples; among them 35 sulfur-containing compounds were detected only in sulfur-fumigated white ginseng and its decoction were assigned to be sulfate or sulfite derivatives of original ginsenosides. These were deduced to be generated via reactions of esterification, addition, hydrolysis and dehydration during sulfur fumigation and decocting of white ginseng (Li et al. 2012e).

Two panasinsane-type sesquiterpene alcohols, panasinsanol A and panasinsanol B, were isolated from ginseng rootlets together with known sesquiterpene hydrocarbons: α-panasinsene, β-panasinsene, α-neoclovene and β-neoclovene (Iwabuchi et al. 1987). Their syntheses from (−)-β-caryophyllene were established. A novel sesquiterpene alcohol named ginsenol was isolated from the rootlets and its structure established as (1*R*,4*S*,7*R*, 11*S*)-3,3,7,11-tetramehtyltricyclo-[5.4.0.0$^{4.11}$]undecan-1-ol (Iwabuchi et al. 1988). A tricarboxylic sesquiterpenoid, isolated from the ethereal extract of ginseng, showed almost identical nuclear magnetic resonance data to those reported for senecrassidiol (Iwabuchi et al. 1990).

Three β-carboline alkaloids, namely, N_9-formylharman, ethyl B-carboline-1-carboxylate and perlolyrine, were isolated from ginseng and 12 alkaloids detected (Han et al. 1986). An alkaloid 4,5,6,7-tetrahydroimidazo(4,5-c) pyridine-6-carboxylic acid or spinacine was isolated from ginseng roots (Han et al. 1987). Two carboline alkaloids were isolated from an ether-soluble alkaloidal fraction of ginseng and identified as 1-carbobutoxy- β -carboline and 1-carbomethoxy- β -carboline (Park et al. 1987). From the ether-soluble alkaloidal fraction of *Panax ginseng*, 4-methyl-5-thiazoleethanol, norharman and harman were isolated (Park et al. 1988). Three sesquiterpene hydrocarbons were isolated from ginseng root essential oil and identified as (1*R*,2*S*,5*S*)-2-ethenyl-1(1-methylethenyl)-2,6,6-trimethylbicyclo[3.2.0]heptane (panaxene), (1*S*,8*S*,11*R*)-4,7,7,11-tetramethyltricyclo[6.3.0.0(1,5)]undec-4-ene (panaginsene) and (1*R*,6*R*,7*R*)-3,7,10,10-tetramethyltricyclo[4.3.2.0(2,6)]undec-2-ene (ginsinsene) (Richter et al. 2005). A characteristic fragrant and sweet aroma compound was isolated from red ginseng and identified as 3-hydroxy-2-methyl-pyran-4-one (Lee et al. 2005).

*Pg*γ-thionin protein was found to be localised to cell wall-bound extracellular spaces and to be ubiquitously expressed in the leaf, flower bud, stem, root and rhizome, with its highest expression in the roots of *P. ginseng* (Lee et al. 2011). *Pg*γ-thionin contained two exons coding a 225-bp open reading frame with its deduced 75 amino acid sequence interrupted by 1 internal intron. *Pg*γ-thionin was responsive to both biotic and abiotic stresses.

Leaf–Stem Phytochemicals

Ginseng leaf–stem extract contained numerous active ingredients, such as ginsenosides,

polysaccharides, triterpenoids, flavonoids, volatile oils, polyacetylenic alcohols, peptides, amino acids and fatty acids (Wang et al. 2009a). The extract contained larger amounts of the same active ingredients than the root.

A new natural flavonoid, named panasenoside, together with kaempferol and trifolin (kaempferol-3-*O*-galactoside) was isolated from ginseng leaves and stem (Komatsu et al. 1969). Saponins such as ginsenosides Rb_1 and Rg_1 and sapogenins such as panaxadiol, panaxatriol and oleanolic acid were obtained from ginseng petiole callus grown on Murashige and Skoog's agar medium (minus glycine) supplemented with 2,4-dichlorophenoxyacetic acid (Furuya et al. 1973). The saponins were similar to those of ginseng roots. Phytosterols simultaneously obtained were shown to be a mixture of a large amount of β-sitosterol and smaller amounts of stigmasterol and campesterol. Saponins I, II and III were isolated from ginseng stem (Yang 1987).

From ginseng leaves, six saponins – I, II, III, IV, V and VI – were isolated (Yahara et al. 1976b). Saponins IV, V and VI were proved to be identical, respectively, with ginsenosides Rg1, Re and Rd isolated from ginseng roots. The high contents of these saponins in the leaves indicated significance of the leaves as the source of the dammarane-type saponins and their sapogenins. New saponins I, II and III designated as ginsenosides-F1, -F2 and -F3 were established as 20-*O*-β-glucopyranosyl-20 (*S*)-protopanaxatriol, 3,20-di-*O*-β-glucopyranosyl-20 (*S*)-protopanaxadiol and 20-*O*-(α-arabinopyranosyl-(1→6)-β-glucopyranosyl)-20 (*S*)-protopanaxatriol, respectively. Ginsenosides Rb_1, Rb_2 and Rc were isolated from the leaves (Yahara et al. 1979). Four minor compounds were isolated from the leaves and were characterised as 20(*R*)-protopanaxatriol; daueosterin; 3β, 12β-dihydroxy-dammar-20(22), 24-diene-3-*O*-β-D-glucopyranoside (named as ginsenoside Rh_3); and 20(*R*)-protopanaxadiol-3-*O*-β-D-glucopyranoside (named as 20(R)-ginsenoside Rh_2) (Cheng et al. 1987). Two minor compounds 20(*R*)-protopanaxadiol and ginsenoside Rg_4 with the structure 3β, 6α, 12β-trihydroxydammar-20 (22), 24-diene-6-*O*-α-L-rhamnosyl-(1→2)-β-D-glucopyranoside were isolated from the leaves (Zhang et al. 1989a). A novel minor saponin, named ginsenoside La, was isolated from ginseng leaves, and its structure was determined to be a diglucoside of 23-oxygenated protopanaxadiol derivative (Zhang et al. 1989b). A new minor saponin named ginsenoside La was isolated from the leaves (Chen et al. 1990). Six new minor saponins, named as ginsenosides Rh_5, Rh_6, Rh_7, Rh_8, Rh_9 and Rg_7, together with known ginsenosides, namely, majoroside F_2, ginsenoside RH_1, chikusetsusaponin L_8, notoginsenoside Fe, majoroside F_4, 20(*R*)-ginsenoside Rh_1, ginsenoside F_1, ginsenoside F_2, ginsenoside F_3, ginsenoside Rg_1, ginsenoside Re, ginsenoside Rd, ginsenoside Rc and ginsenoside Rb_2, were isolated from the leaves (Dou et al. 2001). The structures of the new saponins were elucidated as follows: ginsenoside Rh_5: 3β,6α,12β,24zeta-tetrahydroxy-dammar-20(22), 25-diene 6-*O*-β-D-glucopyranoside; ginsenoside Rh_6: 3β,6α12β,20(S)- tetrahydroxy-25-hydroperoxy-dammar-23-ene 20-*O*-β-D-glucopyranoside; ginsenoside Rh_7: 3β,7β,12β,20(*S*)-tetrahydroxy-dammar-5,24-diene 20-*O*-β-D-glucopyranoside; ginsenoside Rh_8: 3β,6α,20(*S*)-trihydroxy-dammar-24-ene-12-one 20-*O*-β-D-glucopyranoside; ginsenoside Rh_9: 3β,6α,20(*S*)-trihydroxy-12β,23-epoxy-dammar-24-ene 20-*O*-β-D-glucopyranoside; and ginsenoside Rg_7: 3-*O*-β-D-glucopyranosyl 3β,12β,20(*S*),24(*R*)-tetrahydroxy-dammar-25-ene 20-*O*-β-D-glucopyranoside.

Two compounds isolated from ginseng leaves were identified as 3β,6α,12β-triol-22,23,24,25,26,27-hexanordammaran-20-one and dammar-20(22),24-diene-3β,6α,12β-triol (Wu et al. 2007). A new compound, 3,6,20(*S*)-trihydroxy-12,23-epoxydammar-24-ene,6,20-di-*O*-β-D-glucopyranoside, was isolated from ginseng leaves (Wang et al. 2008). Eleven compounds were isolated from ginseng stem and leaves and identified as β-sitosterol; daucosterol; docosanoic; dammar-24-ene-3β,6α,12β,20(*R*)-tetraol; 20(*R*)-ginsenoside Rh_2; 20(*S*)-ginsenoside Rh_2; 20(*R*)-ginsenoside Rh_1; 20(*S*)-ginsenoside Rh_1; 20(*S*)-ginsenoside Rg_3; 20(*S*)-ginsenoside Rg_2; and 20(*R*)-dammaran-3β,6α,12β,20,25 pentol (Shen et al. 2008). Three new dammarane-type triterpene ginsenosides, ginsenoside Rh_{11},

ginsenoside Rh_{12} and ginsenoside Rh_{13}, together with six known ginsenosides, were isolated from the leaves, and their structures were elucidated as (20S)-3β,6α,12β,20-tetrahydroxydammara-25-ene-24-one 20-*O*-β-D-glucopyranoside (1), (20S)-3β,12β,20,24,25-pentahydroxydammarane 20-*O*-β-D-glucopyranoside (2) and (20S,23E)-3β,12β,20,25-tetrahydroxydammara-23-ene 20-*O*-β-D-glucopyranoside (3), respectively (Liu et al. 2010a). The known ginsenosides were identified as ginsenoside $M(_7cd)$, ginsenoside Rg_6, ginsenoside Rb_3, gypenoside XVII, gypenoside IX and 20-(*E*)-ginsenoside F_4. Two new dammarane-type saponins, named ginsenoside Ki and ginsenoside Km, along with 15 known ones, namely, ginsenoside Re, ginsenoside Rg1, notoginsenoside R_1, floralginsenoside M, floralginsenoside N, ginsenoside F_1, ginsenoside F_5, ginsenoside F_3, vinaginsenoside R_4, ginsenoside Ia, ginsenoside Rd, ginsenoside Rc, ginsenoside Rb_2, ginsenoside Rb_1 and ginsenoside Rh_1, were isolated from the leaves of *Panax ginseng* (Tung et al. 2009). Three new dammarane-type glycosides, named ginsenosides SL_1–SL_3, and 11 known compounds – (20*S*)-ginsenoside Rh_1, ginsenoside F_1, ginsenoside Rh_4, (20*S*)-ginsenoside Rg_2, (20*R*)-ginsenoside Rg_2, ginsenoside Rg_6, ginsenoside F4, ginsenoside Rh3, ginsenoside Rk_2, (20*S*)-ginsenoside Rh_2 and (20*R*)-ginsenoside Rh_2 – were isolated from the heat-processed ginseng leaves (Tung et al. 2010d). Three new dammarane-type triterpene saponins ginsenosides Rh_{18}, Rh_{19} and Rh_{20}, along with two new triterpene sapogenins 12β,23(*R*)-epoxydammara-24-ene-3*β*,6α,20(*S*)-triol and dammara-(20*E*)22,25-diene-3*β*,6α,12*β*,24*S*-tetrol, were isolated from ginseng stems and leaves (Li et al. 2012d). Three dammarane triterpenes, including two new compounds 27-demethyl-(*E*,*E*)-20(22),23-dien-3β,6α,12β-trihydroxydammar-25-one and 3β,20(*S*)-dihydroxydammar-24-en-12β,23β-epoxy-20-*O*-β-D-glucopyranoside, were isolated from ginseng leaves (Tran et al. 2014).

The total saponin content of the leaves analysed on 15th April, 25th April, 5th May and 25th May were 97.29, 66.42, 67.61 and 36.24 mg/g, respectively, in which the content of Re, Re_1 and Rd was more than two third amount of total saponin (Choi et al. 2009). The saponin content of leaves decreased according to the sequential collection days, in which the similar results were observed from the flowers and stems of ginseng. The total saponin content in above-ground parts of ginseng was in the order leaves > flowers > stems. The total saponin content of the stem was 13.32, 9.85, 8.00 and 4.65 mg/g, respectively. The content of Re, Rg_1 and Rd in stems was more than 9/10 amount of total saponins. Ginseng leaf samples were found to contain flavonoid (panasenoside), 2.03–7.40 mg/g, and saponins (ginsenosides Rg1, Re, Rf, Rg2, Rb_1, Rc, Rb_2, Rb_3 and Rd), 59.14–111.55 mg/g, and a few samples contain polyacetylenes (panaxydol and panaxynol) (Qian et al. 2009).

Four anticomplementary polysaccharides, GL-PI to GL-PIV, were isolated from ginseng leaves (Gao et al. 1988). These four polysaccharides possessed a rhamnogalacturonan backbone consisting of 4-linked GalA and 2-linked Rha*p*. Some 6-linked Gal*p* was attached to GalA or GlcA.GL-PI had the highest molecular weight which is 50,000. GL-PI and GL-PII consisted mainly of Rha, Gal and GalA, and GL-PIII contained Fuc in addition, whereas GL-PIV consisted mainly of Gal, Glc and GalA. GL-PI and GL-PII contained mainly (1→2)-linked Rha*p* and (1→4)-linked GalA. GL-PII contained, in addition, 2,4-di-*O*-substituted Rha*p*, nonreducing terminal Gal*p* and (1→6)-linked Gal*p* as the major glycosidic linkages. GL-PIV also contained mainly (1→4)-linked GalA, nonreducing terminal Gal*p* and (1→6)-linked Gal*p*, whereas GL-PIII contained mainly nonreducing terminal GalA and 3,4-di-*O*- and 2,4-di-*O*-substituted GalA, in addition to (1→4)-linked GalA and (1→2)-linked Rha*p*. Three potent anticomplementary polysaccharides, GL-PI, GL-PII and GL-PIV, were isolated from ginseng leaves (Gao et al. 1990). β-Eliminative degradation of GL-PI and GL-PII each afforded neutral (IN and IIN) and acidic (IA and IIA) fractions. Each fraction N consisted of Ara, Rha, Gal and Glc, whereas each fraction A comprised a large proportion of GalA in addition to Rha, Gal, Glc and GlcA. Fractions IN and IIN contained Rha-(1→2)-Rha-ol-1-d,

Rha-(1→4)-Rha-ol-1-d, Ara-(1→4)-Rha-ol-1-d, Gal-(1→4)-Rha-ol-1-d, Gal-(1→6)-Gal-ol-1-d and GlcA-(1→4)-Rha-ol-1-d, and fractions IA and IIA contained Rha→Rha-ol-1-d, HexA→Rha-ol-1-d and HexA→-Rha→Rha-ol-1-d. IN and IIN also contained high molecular weight 6-linked galactan and 4-linked glucan, and IA and IIA consisted mainly of 2-linked Rha, 4-linked GalA and terminal and 6-linked Gal. IIA contained more 2-linked Rha than IA. GL-PIV contained a high molecular weight fraction (PG-1) which was rich in neutral sugars, fragments of intermediate size (PG-2) and oligosaccharides (PG-3). PG-1 contained a rhamnogalacturonan core, galactan (which mainly comprised of terminal 6-linked and 4,6-disubstituted Gal) and 4-linked glucans. PG-2 contained (1→4)-linked α-galacturonan partially branched at position 2 or 3 and a rhamnogalacturonan core in addition to small proportions of Gal and Glc. PG-3 contained large proportions of oligogalacturonides. *Panax ginseng* extract G-115 had anticomplementary activity, and the major potent anticomplementary polysaccharide, G-115I_1-IIa-2-3, was obtained from the extract (Yamada et al. 1995). G-115I_1-IIa-2-3 was homogeneous, and its molecular weight was estimated to be 3.68×10^5. G-115I_1-IIa-2-3 consisted mainly of arabinose, galactose and glucose in addition to small amounts of galacturonic acid, glucuronic acid and rhamnose.

An antiulcer polysaccharide (GL-BIII) was purified from ginseng leaves (Kiyohara et al. 1994). GL-BIII consisted mainly of terminal Arap, 4- or 5-substituted Ara, 2,4-disubstituted Rha, 4- and 6-substituted Gal and 3,6-disubstituted Ga and also contained terminal 4-substituted and 3,4-disubstituted GalA and terminal and 4-substituted GlcA. Some 2-substituted Rha in GL-BIII was attached to position 4 of a 4-substituted uronic acid. GL-BIII also contained a small proportion of a β-(1→3,6)-galactan moiety, a GalA-(1→4)-Rha unit in addition to longer acidic units consisting of 2-substituted Rha and 4-substituted GalA. Fractions of GL-BIII were found to contain long and intermediate neutral oligosaccharide-alditols and a large amount of a fraction containing short oligosaccharide-alditols. The long neutral oligosaccharide-alditol fraction mainly comprised of 4- or 5-substituted Ara, terminal Gal*f*, 6-substituted Glc and 2-substituted Man, whereas the intermediate oligosaccharide-alditol fraction consisted mainly of terminal and 6-substituted Gal*p*, 6-substituted Glc and 2-substituted Man.

A complex pectic polysaccharide (GL-4IIb2) was isolated from ginseng leaves (Shin et al. 1997). GL-4IIb2 consisted of 15 different monosaccharides which included rarely observed sugars, such as 2-*O*-methylfucose, 2-*O*-methylxylose, apiose, 3-C-carboxy-5-deoxy-L-xylose (acetic acid, AceA), 3-deoxy-D-manno-2-octulosonic acid (Kdo) and 3-deoxy-D-lyxo-2-heptulosatic acid (Dha). Another three different polysaccharides, GL-RI, GL-RII and GL-RIII, were isolated from polysaccharide subfraction GL-5 from ginseng leaves (Shin et al. 1998). The three polysaccharides consisted of the same substitution patterns of 2-*O*-methyl-fucose, 2-*O*-methyl-xylose, apiose, 3-*C*-carboxy-5-deoxy-L-xylose (aceric acid, AceA), 3-deoxy-D-manno-2-octulosonic acid (Kdo) and 3-deoxy-D-*lyxo*-*2*-heptulosaric acid (Dha), being characteristic monosaccharides of rhamnogalacturonan-II, but no other pectic components.

Purification of the weakly acidic polysaccharide fraction, GL-4 (from ginseng leaves), yielded the bioactive polysaccharide, GL-4IIb1III, with average relative molecular mass 16,000 Da, and comprising a pectic polysaccharide composed mainly of galactose and galacturonic acid with small proportions of rhamnose, arabinose, mannose, glucose and glucuronic acid (Sun et al. 1992b). Three flavonoids – kaempferol, sophoraflavonoloside and prunin – were isolated from the leaves (Tung et al. 2010b). Panasenoside [kaempferol-3-*O*-β-D-glucopyranosyl(1→2)-β-D-galactopyranoside] was extracted from ginseng leaves, and the average recovery was 98.5 % (Li et al. 2010b).

Flower Phytochemicals

A new natural flavonoid, named panasenoside, was isolated from ginseng buds (Komatsu et al. 1969). Ginsenosides Rd, Re and Rg_1 were isolated from dried mixture of ginseng buds and flowers (Yahara et al. 1976a). Ginsenoside Re was isolated in high yield of ca 2.5 %. A new saponin ginsenoside M7cd with the structure established as 20-*O*-β-D-glucopyranoside of dammar-25-ene-3β, 6α, 12β, 20 (*S*), 24ζ-pentaol was isolated from ginseng flower bud together with ginsenosides Rb_1, Rb_2, Rc and F_3 (Yahara et al. 1979). Ginsenoside Rb_3 and ginsenoside Rc were isolated from the flower buds (Shao 1984). Two tetracyclic triterpenic saponins, FC1 and FD3, were isolated from ginseng flower buds and the structures established as ginsenoside Rb_2 and 20-glucoginsenoside Rf (Shao et al. 1984). From flower buds of *P. ginseng*, ginsenosides Ro (=chikusetsusaponin V), Rb_1, Rb_2, Rb_3, Rc, Rd and Re; 20-glucoginsenoside Rf; and ginsenosides Rf, Rg_1 and Rg_2 were isolated (Shao et al. 1989). Thirteen compounds were identified from ginseng flower buds: β-sitosterol, daucosterine, ginsenoside Rh_1, 20-(*S*)-ginsenoside Rg_2, 20-(*R*)-ginsenoside Rg_2, ginsenoside Rf, ginsenoside Re, ginsenoside Rg_3, ginsenoside Rd, ginsenoside Rc, ginsenoside Rb_2, palmitic acid and *trans-p*-hydroxy-cinnamic acid (Wang et al. 1992). Eleven of 15 compounds, isolated from ginseng flower buds, were identified: β-sitosterol, 20(*R*)-protopanaxatriol, 20(*R*)-ginsenoside Rh_1, 20(*R*)-ginsenoside Rg_2, 20(*S*)-ginsenoside Rg_2, ginsenoside Re, ginsenoside Rd, ginsenoside Rc, ginsenoside Rb_2, gypenoside XVII and notoginsenoside-E (Qui et al. 1997). A new minor dammarane-type triterpene saponin named ginsenoside III together with nine known saponins was isolated from dried flower buds (Qui et al. 1998). The structure of the new saponin was elucidated as 3-*O*-[β-D-glucopyranosyl(1→2)-β-D-glucopyranosyl]-20-*O*-β-D-glucopyranosyl-3β,12β,20(S)-trihydroxy-dammar-25-en-24-one. A pair of new 24-epimers of dammarane-type saponins named ginsenosides I and II were isolated from ginseng flower buds (Qui et al. 2001). The structures of the epimers were characterised as 3-*O*-[β-D-glucopyranosyl-(1→2)-β-D-glucopy-ranosyl]-20-*S*-*O*-β-D-glucopyranosyl-3β, 12β,20(*S*)-trihydroxy-24xi-hydroperoxydammar-25-ene, except for their C-24 configurations.

From the oligoglycoside fraction of ginseng flower buds, new dammarane-type triterpene tetraglycosides, floralginsenosides M, N, O and P, were isolated together with the major oligoglycosides ginsenoside Rd and Re (Yoshikawa et al. 2007b). Six new dammarane-type triterpene diglycosides with a hydroperoxide group, floralginsenosides A, B, C, D, E and F, were isolated from ginseng flower and flower buds together with seven known dammarane-type triterpene oligoglycosides ginsenoside F1, ginsenoside F3, ginsenoside F5, ginsenoside RG1, ginsenoside RG2, gypenoside XVII and pseudoginsenoside RC1 (Yoshikawa et al. 2007a). New dammarane-type triterpene triglycosides, floralginsenosides G, H, I, J, K, La and Lb, were isolated from the flower buds together with ten known dammarane-type triterpene oligoglycosides (Nakamura et al. 2007). Ginsenosides found in the flower buds included Rb_1, Rb_2, Rc, Rd, Re and RG_1 (Sugimoto et al. 2009). The content of ginsenosides in *P. ginseng* flower buds was reported by Ko et al. (2011) as follows: Rb_1 1.104 %, Rb_2 0.669 %, Rc 0.565 %, Rd 0.942 %, Re 3.445 %, Rf 0.046 %, Rg_1 0.421 % and Rg_2 0.0955 – total ginsenosides 7.30 % PD (protopanaxadiol)/PT (protopanaxatriol) 0.82. Six dammarane-type saponins, including three new compounds, floralginsenosides Ta–Tc, and three known, floralginsenoside Td, ginsenoside F_1 and ginsenoside F_5, were isolated from ginseng flower buds (Tung et al. 2010c). Chemical components of steamed flower buds included a new dammarane-type saponin named ginsenoside SF and 19 known compounds, namely, ginsenoside Rh_4, ginsenoside Rk_3, ginsenoside F_1, (20*E*)-ginsenoside F_4, ginsenoside Rg_2, pseudoginsenoside RC_1, ginsenoside Rg6, ginsenoside F_4, ginsenoside Rg_1, 6′-acetyl- ginsenoside Rg_1, ginsenoside Rd, ginsenoside Rc, ginsenoside Rb2, ginsenoside Re,

vinaginsenoside R_4, ginsenoside Mb, ginsenoside Rb_1, ginsenoside Rs_4 and 6′acetyl-ginsenoside F_1 (Tung et al. 2010a). Three new dammarane-type saponins, named floralginsenosides Ka, Kb and Kc, along with 17 known ones, were isolated from ginseng flowers (Tung et al. 2010e). The total saponin contents of the flowers analysed on 15th April, 25th April, 5th May and 25th May were 141.09,143.84,139.25 and 133.47 mg/g, respectively, in which the content of Re, Rd and Rb_2 in flowers accounted for more than 2/3 amount of total saponins (Choi et al. 2009).

A ribonuclease, with a molecular mass of 23 kDa and much higher activity towards poly(U) than poly(C) and only negligible activity towards poly(A) and poly(G), was isolated from the aqueous extract of Chinese ginseng flowers (Wang and Ng 2004).

Fruit/Seed Phytochemicals

Ginsenosides Rb_2, Rc, Rd, Re and Rg_1 were isolated from the fruits; ginsenoside Re was obtained in high yield of 6 % (Yahara et al. 1979). Eleven saponins were extracted from *P. ginseng* fruits and identified as 20(*R*)-dammarane-3β,12β,20,25-tetrol (25-OH-PPD); 20(*R*)-dammarane-3β,6α,12β,20,25-pentol (25-OH-PPT); 20(*S*)-protopanaxadiol (PPD); daucosterine; 20(*S*)-ginsenoside Rh_2 (Rh_2); 20(S)-ginsenoside Rg_3 (Rg_3); 20(S)-ginsenoside Rg_2 (Rg_2); 20(*S*)-ginsenoside Rg*1* (Rg_1); 20(*S*)-ginsenoside Rd (Rd); 20(*S*)-ginsenoside Re (Re); and 20(*S*)-ginsenoside Rb*1* (Rb_1) (Wang et al. 2007). Ginsenosides found in the mature fruit flesh included Rb_1, Rb_2, Rc, Rd, Re and RG_1; Rd was not detected in flesh of young fruit (Sugimoto et al. 2009).

A new dammarane-type triterpene ketone, panaxadione, was isolated from ginseng seeds together with 20(*S*)-protopanaxatriol; 3-keto-20(*S*)- protopanaxatriol; 3β-*trans*-feruloyloxy-16β-hydroxyup-20(29)-ene; daucosterol; 5α-,6β-dihydroxydaucosterol; saringosteryl glucoside; phenethyl alcohol xylopyranosyl(1→6)glucopyranoside; and ginsenosides Rg_2, Re and Rd (Sugimoto et al. 2009). A new phenolic glucoside, isoconiferoside, was isolated from ginseng seeds, and its structure was determined to be 9-*O*-β-D-glucopyranosyl-(1→6)-β-D-glucopyranosyl]-*trans*-coniferyl alcohol (Kim et al. 2011b). Three new dammarane-type sapogenins, 20(*R*)-25-methoxyl-dammarane-3β,12β,20-triol, 20(*R*)-20-methoxyl-dammarane-3β,12β,25-triol and (12*R*,20*S*,24*S*)-20,24-; 12,24-diepoxy-dammarane-3β-ol, together with two known ones, 20(*R*)-25-methoxyl-dammarane-3β,6α,12β,20-tetrol and 20(*R*)-20,25-dimethoxyl-dammarane-3β,12β-diol, were isolated from ginseng berry (Zhao et al. 2011).

The ginseng seed oil yield showed that the yield was higher in roasted ginseng seed compared to that of unroasted ginseng seeds (Lee et al. 2013e). The yield of ginseng seed oil was 16.53 % with compress extraction (200 °C, 20 minutes), 13.7 % with n-hexane solvent extraction (200 °C, 30 minute) and 17.48 % with supercritical fluid extraction (SFE) (500 bar, 65 °C). Based on the preceding extraction conditions, fatty acid (g/100 g) of seed oil from compress extraction was palmitic acid (16:0) 2 g, stearic acid (18:0) 0.3 g, palmitoleic acid (16:1) 0.3 g, oleic acid (18:1) 79.8 g, linoleic acid (18:2) 16.2 g, linolenic acid (18:3) 0.1 g and gadoleic acid (20:1) 0.1 g unknown 1.2 %; for n-hexane solvent extraction palmitic acid 2 g, stearic acid 0.3 g, palmitoleic acid 0.2 g, oleic acid 79.7 g, linoleic acid 16.3 g, linolenic acid 0.1 g and gadoleic acid 0.1 g unknown 1.2 %; for SFE palmitic acid (16:0) 2 g, stearic acid (18:0) 0.3 g, palmitoleic acid (16:1) 0.3 g, oleic acid (18:1) 79.8 g, linoleic acid (18:2) 16.2 g, linolenic acid (18:3) 0.1 g and gadoleic acid (20:1) 0.1 g unknown 1.2 %; for n-hexane solvent extraction palmitic acid 1.9 g, stearic acid 0.3 g, palmitoleic acid 0.3 g, oleic acid 79.8 g, linoleic acid 16.3 g, linolenic acid 0.1 g and gadoleic acid 0.1 g unknown 1.2 %. Phenolic acids detected in ginseng seed oil were gentisic acid, vanillic acid, ferulic acid and cinnamic acid. Ferulic and cinnamic acids were detected following compression extraction, with almost no difference in content depending on the roasting treatment. Cinnamic acid was detected at 0.007–0.029 μg/g, and gentisic acid was detected at 1.438 μg/g in unroasted ginseng seed

oil following solvent extraction. The phenolic acids detected in ginseng seed oil following supercritical fluid extraction were vanillic and ferulic acids, and the vanillic acid content tended to decrease as pressure and temperature increased. Stigmasterol and β-sitosterol were obtained from all extraction methods. A phytosterol content analysis in ginseng seed oil showed that the phytosterol content of oil following supercritical fluid extraction was 100.4–135.5 mg/100 g, whereas that following compression extraction and solvent extraction was 71.8–80.9 mg/100 g. A new sterol glucoside, 3-*O*-β-D-glucopyranosyl-5,22,24-stigmastatrienol and a known sterol, 5,22-stigmastadienol were isolated from ginseng seeds (Kim et al. 2013e).

Plant/Calluses Phytochemicals

Free indole-3-acetic acid was identified and extracted from ginseng calluses (Nishio et al. 1976). A water-soluble polysaccharide was isolated from ginseng callus culture with a yield of 16–20 % (Solov'eva et al. 1989). It comprised of starch A and acidic polysaccharides – arabinogalactans and a xyloglucan. Among neutral monosaccharides found, galactose and arabinose predominated and, in addition to these, there were glucose, xylose and rhamnose. The polysaccharides also contained uronic acid residues. Triterpene saponins (ginsenosides) were the main bioactive compounds in *P. ginseng* (Kim et al. 2014e). The isoprene units of triterpene were derived from the mevalonic acid (MVA) pathway. The ginsenosides RG1, RE, Rf, Rg2, Rh1, Rb1, Rc, Rb2, Rb3 and Rd were found in the ginseng red berry, leaf, petiole, stem, main root, lateral root and fine root. The total ginsenoside contents in different organs were ranked in the following descending order: leaf > fine root > lateral root > red berry > main root > petiole > stem. The transcript levels of 11 genes involved in the terpenoid pathway in different organs and cell suspension cultures of *P. ginseng* were investigated: HMGS, HMG-CoA synthase; MVD, mevalonate diphosphate decarboxylase; SE, squalene epoxidase; CAS, cycloartenol synthase; HMGR, 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA) reductase; FPS, farnesyl diphosphate synthase; β-AS, beta-amyrin synthase; SS, squalene synthase; DDS, dammarenediol-II synthase; PMK phosphomevalonate kinase; and lanosterol synthase. Four genes involved in the MVA pathway were cloned using rapid amplification of cDNA ends by polymerase chain reaction. The full-length cDNA sequences were as follows: PgHMGS (1,764 bp; 1,407-bp ORF), PgHMGR (1,992 bp; 1,722-bp ORF), PgPMK (2,170 bp; 1,530-bp ORF) and PgMVD (1,759 bp; 1,263-bp ORF). Campesterol and stigmasterol were detected in all organs but at different concentrations. Cholesterol was found only in the lateral and fine root. The total phytosterol content was highest in fine root (147.8 μg/100 mg dry weight (DW)) and was lowest in the stem (86.4 μg/100 mg DW). β-amyrin was found in the red berry, lateral and fine root.

Pharmacological Activities Overview

Studies had demonstrated the pharmacological efficacy of ginseng in improving cerebral function, enhancing immune system and liver functions, adjusting blood pressure, improving climacteric disorder and sexual functions, as well as its pain-relieving, antitumour, antidiabetic, antifatigue, antistress, antioxidative and anti-ageing effects (Choi 2008). The number of ginsenoside types contained in Korean ginseng (38 ginsenosides) is substantially more than that of ginsenoside types contained in American ginseng (19 ginsenosides). Furthermore, Korean ginseng had been identified to contain more main non-saponin compounds, phenol compounds, acid polysaccharides and polyethylene compounds than American ginseng and Sanchi ginseng. Takagi et al. (1972a, b) had reviewed the pharmacological properties of ginseng extracts such as hypotensive, analeptic, stimulatory activity on central nervous system, the respiration and the adrenal cortex, motility of digestive system and correction of nutritional disorders. *P. ginseng* is the most commonly used as an adaptogenic agent and has been shown to enhance physical

performance, promote vitality, increase resistance to stress and ageing and has immunomodulatory activity (Kim 2012). Ginseng leaf–stem extract had also been reported to have antifatigue, antihyperglycaemic, antiobesity, anticancer, antioxidant and anti-ageing properties (Wang et al. 2009a).

Antioxidant Activity

In-Vitro Studies

Ginseng extract scavenged hydroxyl radical by the Fenton reaction and directly inhibited unsaturated fatty acids from decomposition caused by iron-mediated lipid peroxidation as shown by the inhibition of thiobarbituric acid reactive substances (TBARS) and loss of arachidonic acid (Zhang et al. 1996). Heat treatment of ginseng at a temperature higher than that applied to the conventional preparation of red ginseng yielded a mixture of saponins with potent antioxidative properties (Keum et al. 2001). Thus, the methanol extract of heat-processed neo-ginseng (designated as "NGMe") attenuated lipid peroxidation in rat brain homogenates induced by ferric ion or ferric ion plus ascorbic acid. The extract protected rats against strand scission in øX174 supercoiled DNA induced by UV photolysis of H_2O_2 and was also capable of scavenging superoxide generated by xanthine–xanthine oxidase or by 12-*O*-tetradecanoylphorbol-13-acetate (TPA) in differentiated human promyelocytic leukaemia (HL-60) cells.

In in-vitro studies, ginseng extract inhibited the formation of glycated haemoglobin; glycation is a well-known cause of various forms of diabetic complications (Bae and Lee 2004). The inhibitory effect could be attributed to the antioxidative activity of ginseng. The extracts of *Panax ginseng* showed a remarkable capacity to protect brain tissue proteins from oxidative damage in-vitro, even at extreme (2,000 kRads) dosage levels of hydroxyl (OH.) or superoxide (O2-.) free radical species generated by cobalt 60 irradiation in-vitro (Siddique et al. 2000). It was suggested, therefore, that the beneficial effect of ginseng extract in preventing brain tissue damage in-vivo (e.g. following ischaemia–reperfusion) may result from their action in protecting brain proteins from oxidative damage, in addition to their previously reported capacity to reduce free radical-induced lipid peroxidation. Ginseng extracts completely eliminated DPPH radical at 2 mg/ml (Kim et al. 2002b). About 0.5 mg/ml ginseng extracts quenched 80 % carbon-centred free radicals generated from 2,2′-azobis(2-amidinopropane) dihydrochloride (AAPH). Ginseng extracts scavenged 40 % of hydroxyl radical at 0.1 mg/ml. Two milligrammes/millilitre ginseng extracts completely scavenged superoxide radical. Ginseng extracts did not scavenge nitric oxide. Of two neutral polysaccharide fractions GPII and GPIII from ginseng extract, GPII exhibited equivalent inhibiting power for self-oxidation of 1,2,3-phentriol to vitamin C, a little higher scavenging activity of superoxide radical and hydroxyl radical than vitamin C, and could be explored as a novel potential antioxidant (Luo and Fang 2008).

Among various solvent extracts in cultivated and wild ginseng leaves, ethyl acetate (EA) extracts in both cultivated and wild ginseng leaves showed the most powerful scavenging activities against DPPH radicals (Jung et al. 2005b). Data on other antioxidant activities, measured by inhibition rates against lipid peroxidation and linoleate oxidation, revealed similar results, showing the highest activities in EA extracts, followed by butanol, water, chloroform and hexane extracts, in both cultivated and wild ginseng leaves. EA extracts of wild ginseng leaves contained more phenolics than cultivated ginseng leaves (9.71 g vs. 4.87 g/100 g, dry basis) and flavonoids (3.03 g vs. 2.34 g/100 g, dry basis). When EC extracts were acid-hydrolysed, two aglycones of flavonoids, quercetin (0.43 and 0.66 g/100 g, dry basis) and kaempferol (1.23 and 1.50 g/100 g, dry basis), were detected in cultivated and wild ginseng leaves. Water, methanol and ethanol extracts of freeze-dried leaves of wild ginseng exhibited antioxidant (free radicals scavenging) activity (Jung et al. 2006). The ethanol extract showed the highest DPPH, hydroxyl radical scavenging and ferrous ion-chelating activity. Otherwise, the highest superoxide radi-

cal scavenging activity was found in water extract followed by ethanol and methanol extracts of wild ginseng leaves. Ethanol extracts contained more phenolics (2,333.2 mg/100 g) and flavonoids (1,199.1 mg/100 g) than other extracts.

Red ginseng (steamed ginseng at 98–100 °C) and sun ginseng (steamed ginseng at 120 °C) showed better superoxide (O^{2-}), peroxynitrite ($ONOO^-$) and hydroxyl (*OH) scavenging activities than white ginseng (WG) (Kang et al. 2006a, b, 2009). Sun ginseng extract showed the strongest activity among the three ginseng extracts. None of the ginsenosides used in this experiment showed nitric oxide (*NO) scavenging activity, but the phenolic compounds, such as *p*-coumaric and vanillic acids, and maltol inhibited *NO production in a concentration-dependent manner. Of the principal antioxidant components, maltol, salicylic acid, vanillic acid, syringic acid and *p*-coumaric acid, in the three ginsengs, maltol, vanillic acid and *p*-coumaric acid exhibited $ONOO^-$ scavenging activity. In addition, maltol and *p*-coumaric acid showed strong *OH scavenging activity. Moreover, maltol levels markedly increased by heat processing. The $ONOO^-$ scavenging activities of phenolic acids and maltol were dependent on the degrees of their proton donating ability.

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Steam treatment of ginseng, white and red ginseng, increased Maillard reaction products (MRPs) and also increased radical 2,2′-azobis-(2-amidinopropane) dihydrochloride (AAPH) scavenging activity (Cho et al. 2008). Further, MRPs-rich fraction in ginseng showed powerful antioxidant activity, indicating MRPs to be major contributors to antioxidant activity enhanced by steam treatment. Antioxidant activities of hydroponic-cultured ginseng roots (HGR) and hydroponic ginseng leaves (HGL) measured by 1,1-diphenyl-2-picrylhydrazyl and 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid radical scavenging ability increased with increasing heating temperature (Hwang et al. 2014). After heating, polyphenol contents of HGR and HGL increased from 0.43 mg GAE eq./g and 0.74 mg GAE eq./g to 6.16 mg GAE eq./g and 2.86 mg GAE eq./g, respectively.

The antioxidant potential of the methanol extracts from ginseng plants dose dependently increased (Chon and Kim 2011). DPPH free radical scavenging activity was higher in leaves (36.9–82.8 %) than in roots (14.8–39.4 %) and in young plants than in old ones. Total phenolics level [mg ferulic acid equivalents (FAE)/kg DW] was higher in leaves (22.0–76.3 mg/kg) than in roots (19.0–28.3 mg/kg) of *P. ginseng*. The total content of phenolics in roots increased with increase in plant age from 1 to 6 years. However, the content of phenolics in *P. ginseng* leaf decreased with the increase in age. Total flavonoid [mg naringin equivalents/kg DW] was found more in leaves (30.3–138.6 mg/kg) than in roots (0.0–10.6 mg/kg). The total flavonoid level in leaves decreased with increase in plant age. The total phenolics content in both leaves and roots was highly correlated with the DPPH radical scavenging ($R^2 = 0.7366–0.7870$) and nitrite scavenging ($R^2 = 0.5604–0.8794$) activities, suggesting that they contribute to the antioxidant properties of the plant.

Heating and solvent use had an impact on the ginsenoside composition and antioxidant activity of fresh ginseng (Hwang et al. 2010). When water

and ethanol were used, the ginsenoside compositions significantly changed at 100 and 121 °C, respectively, and it was rapidly decreased at 150 °C. After heating, the level of three ginsenosides (Re, Rf and Rg1) decreased and that of five other ginsenosides [Rb1, Rb2, Rb3, Rc and Rg2(S)] increased up to 121 °C compared to raw ginseng. Ginsenoside F2, F4, Rg2(R), Rk3, Rh4, Rg3(S), Rg3(R), Rk1 and Rg5, which was absent in raw ginseng, was detected in heated ginseng. Ginsenoside Rg3(S), Rg3(R), Rk1 and Rg5 were markedly produced after thermal processing. After heating, the phenolic compounds (1.43–11.62 mg/g), 50 % inhibition concentration (IC_{50}) value (1.48–3.11 mg/g), and ABTS radical scavenging activity (0.66–9.09 mg AA eq./g) of heated ginseng were increased.

In-vitro antioxidant tests showed that water-soluble ginseng oligosaccharides (WGOS) from roots (WGOS-R) exhibited higher antioxidant activity than WGOS-F from flowers and WGOS-L from leaves (Jiao et al. 2014a). In-vivo antioxidant tests showed that WGOS-R significantly enhanced activities of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GSH-Px) and total antioxidant capability (T-AOC) in the serum and liver and decreased malondialdehyde (MDA) level in the serum and liver. The sugar content of WGOS-R, WGOS-F and WGOS-L were 95.87 %, 87.07 % and 83.09 %, respectively. The ginsenosides and total phenols content decreased in the order of WGOS-L > WGOS-F > WGOS-R. WGOS-R comprised of only Glc; WGOS-F and WGOS-L comprised of glucose (Glc) and rhamnose (Rha) in a molar ratio of 6.0:1.0 and 7.0:1.0, respectively. Among the saponins isolated from ginseng flowers, floralginsenoside Ka displayed potent scavenging activity with the inhibition value of 64 % at 10 μM, and ginsenoside Rb_1, floralginsenoside Kc, floralginsenoside Kb, vinaginsenoside R_9, majoroside F_1, ginsenoside I and ginsenoside II showed moderate scavenging capacity with the inhibition rate of 28, 33, 35, 35, 35, 38 and 38 % at 10 μM, respectively, as evaluated by the intracellular ROS radical scavenging 2′,7′ dichlorofluorescin diacetate (DCFH-DA) assay (Tung et al. 2010e).

Animal Studies

Studies suggested that consumption of Korean red ginseng reduced lipid peroxidation and restored antioxidant capacity by suppressing oxidative stress in aged rats through enhancement of enzymatic antioxidants such as superoxide dismutase, catalase, glutathione peroxidase, glutathione reductase and glutathione-*S*-transferase and nonenzymatic antioxidants such as reduced glutathione, vitamin E and vitamin C (Ramesh et al. 2012a). Won et al. (2014) found that administration of a pectinase-treated *P. ginseng* extract enhanced dysfunctional testicular function of aged rats by elevating GPx and GST activity, thus resulting in increased glutathione, which prevented lipid peroxidation in the testis. Studies showed that ginseng ginsenoside Rg_3 significantly inhibited cyclophosphamide-induced oxidative stress in mice by increasing the indices of the spleen and thymus and total antioxidant capacity, elevating the activities of catalase, superoxidase dismutase and lysozyme as well as decreasing the activity of xanthine oxidase and the levels of malondialdehyde and nitric oxide (Wei et al. 2012). Rg_3 was stereospecific in antioxidant activities as the R form exhibited significantly higher antioxidant effects than the S form.

In-vivo studies showed that ginseng extract modulated oxidative stress and DNA fragmentation and upregulated gene expression in rats subchronically treated with aflatoxin B1 and fumonisin B1 (Hassan et al. 2014). The combined treatments with AFB1 and/or FB1 plus ginseng extract suppressed DNA fragmentation only in the liver, normalised lipid peroxidation and increased glutathione in the liver and kidney as well as upregulated the expression of GPx, SOD1 and CAT mRNA. It could be concluded that AFB1 and FB1 had synergistic genotoxic effects. Ginseng extract induced protective effects against their oxidative stress and genotoxicity through its antioxidant properties.

Clinical Studies

In a double-blind randomised controlled design involving 82 healthy participants (21 men and 61 women), administration of *P. ginseng* led to significant decreases in the levels of serum reactive oxygen species and malondialdehyde (Kim et al. 2011b). Notably, the total glutathione content and glutathione reductase activity considerably improved in the groups that received 2 g of *P. ginseng*. The findings indicated that *P. ginseng* exerted considerably antioxidant properties in healthy people.

Anticancer Activity

In-Vitro Studies

In the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay, the methanol extracts from a 5-year-old ginseng root showed the highest cytotoxicity against human lung adenocarcinoma cell line Calu-6, followed by 2- and 3-year-old ginseng roots (Chon and Kim 2011). However, the methanol extracts from 6- to 4-year-old roots exerted lower cytotoxicity. The 70 % methanolic extract from red ginseng at oral doses of 200–500 mg/kg inhibited solid tumour but was ineffective in the case of rat ascites hepatoma AH 130 (Matsunaga et al. 1992). Ginseng extract when combined with mitomycin C showed a stronger antitumour effect than mitomycin C alone. Moreover, ginseng extract inhibited the pulmonary metastases of the tumour cells, as well as the decrease of blood platelet counts and the fibrinogen level induced by the infusion of the tumour cells in rats. Further, ginseng extract promoted the uptake of mitomycin C into the tumour cells and enhanced in-vitro the cytotoxicity of mitomycin C against the cultured tumour cells. Red ginseng methanol extract combined with mitomycin C showed stronger antitumour effects against the ascites form of mouse Ehrlich ascites carcinoma and rat ascites hepatoma AH 130 than mitomycin C combined with white ginseng methanol extract (Tong et al. 1992). From the ethyl acetate-soluble portion of red ginseng methanol extract, 20(S)- and 20(R)-ginsenoside Rg_3 and ginsenoside Rh_2 were isolated and promoted the uptake of mitomycin C into the tumour cells, but ginsenosides from the n-Bu0H soluble portion had no effect on the tumour cells.

Ginsenosides Rh_1 and Rh_2 cause the differentiation of F9 teratocarcinoma stem cells, and the effects of ginsenosides might be exerted via binding with a glucocorticoid receptor or its analogous nuclear receptor (Lee et al. 1996). They found that Rh_1 and Rh_2 may induce the differentiation of F9 cells by stimulating the nuclear translocation of glucocorticoid receptor (Lee et al. 1998). Further, they found that ginsenosides Rh_2 and Rh_3 induced differentiation of human myeloid leukaemia (HL-60) cells into morphological and functional granulocytes, but ginsenoside Rh_1 and ginsenoside Rh_4 did not (Kim et al. 1998c). Ginsenosides Rh_2 and Rh_3 arrested the cell cycle at the G1/S phase, consistent with the ability to induce differentiation in a decreasing order of retinoic acid > G-Rh2 > G-Rh_3. In-vitro invasion assay showed that ginsenoside Rh_2 reduced the highly metastatic HT1080 human fibrosarcoma cell invasion through a reconstituted basement membrane in a transwell chamber more than ginsenoside Rh_1 (Park et al. 1998b). The results suggested that downregulation of matrix metalloproteinase-9 (MMP-9) contributed to the anti-invasive activity of ginsenosides Rhl and Rh2 in the HT1080 cells. Ginseng saponin metabolite, 20-*O*-β-D-glucopyranosyl-20(*S*)-protopanaxadiol (IH-901), inhibited proliferation of human myeloid leukaemia (HL-60), pulmonary adenocarcinoma (PC-14), gastric adenocarcinoma (MKN-45) and hepatoma (Hep G2) cell lines with IC_{50} values of 24.3, 25.9, 56.6 and 24.9 μM, respectively (Lee et al. 1999). Ginsenoside Rh2 induced apoptosis of human hepatoma SK-HEP-1 cells via Bcl-2-insensitive activation of caspase-3, followed by proteolytic cleavage of PARP (Park et al. 1997). Ginsenoside Rs_4, an acetylated analogue of ginsenoside Rg_5, was found to induce apoptosis in human hepatoma SK-HEP-1 cells; the effect was closely

associated with the downregulation of both cyclins E- and A-dependent kinase activity as a consequence of selectively elevating protein levels of p53 and $p21^{WAF1}$ in SK-HEP-1 cell (Kim et al. 1999d).

Ginseng ginsenoside Rg_3 displayed growth inhibitory activity in-vitro on human prostate carcinoma LNCaP cell line (Liu et al. 2000). Results suggested that ginsenoside Rg_3 activated the expression of cyclin-kinase inhibitors p21 and p27, arrested LNCaP cells at G1 phase and subsequently inhibited cell growth through a caspase-3-mediated apoptosis mechanism. Ginsenoside Rh_2 (G-Rh_2) induced apoptosis in human neuroblastoma SK-N-BE(2) and rat glioma C6Bu-1 cells (Kim et al. 2000). During apoptosis induced by ginsenoside Rh_2 in SK-N-BE(2) cells, PKC subtypes alpha, beta and gamma were progressively increased with prolonged treatment, whereas PKC delta increased transiently at 3 and 6 hours and PKC epsilon was gradually downregulated after 6 hours following the treatment. On the other hand, PKC subtype zeta markedly increased at 24 hours when maximal apoptosis was achieved. In C6Bu-1 cells, no significant changes in PKC subtypes were observed during apoptosis induced by ginsenoside Rh_2. Ginsenoside Rh_2 was found to induce apoptosis independently of Bcl-2, Bcl-xL or Bax in C6Bu-1 cells (Kim et al. 1999g).

Among ginsenoside Rg3 and its metabolites, 20(S)-protopanaxadiol and 20(S)-ginsenoside Rh2 exhibited the most potent cytotoxicity against tumour cell lines: L1210 (mouse lymphocytic leukaemia cell line), P388 (mouse lymphoid neoplasm cell line), A549 (human lung carcinoma) and Me180 (human cervix uterine carcinoma) with IC_{50} values of 18–33 μM and 22–33 μm, respectively (Bae et al. 2002b). 20-*O*-(β-D-glucopyranosyl)-20(*S*)-protopanaxadiol (IH901), an intestinal bacterial metabolite of ginseng saponin formed from ginsenosides Rb1, Rb2 and Rc, was found to induce apoptosis in human hepatoblastoma HepG2 cells via a mitochondria-mediated pathway and its downstream caspase-8 activation and Bid cleavage (Oh and Lee 2004). The very low toxicity in normal hepatocytes and high activity in hepatoblastoma HepG2 cells suggested IH901 to be a promising experimental cancer chemopreventive agent.

Acid-treated ginseng (AG) extract, fermented AG extract, ginsenoside Rh_2 and protopanaxadiol showed potent cytotoxicity against tumour cell lines (Bae et al. 2004). Red ginseng ginsenoside Rg_3, inhibited [3H] vinblastine efflux and reversed p-glycoprotein-mediated multidrug resistance to doxorubicin, colchicine, vincristine and VP-16 in drug-resistant cancer KBV20C cells (Kim et al. 2003c). Further, Rg_3 increased lifespan in mice implanted with doxorubicin-resistant murine leukaemia P388 cells in-vivo and inhibited body weight increase significantly. Protopanaxatriol ginsenosides (PTG), ginsenosides Rb1, Rb2, Rc, Rg1 and Re, showed cytotoxicity in both daunorubicin- and doxorubicin-resistant acute myelogenous leukaemia sublines (AML-2/D100 and AML-2/DX100) and was able to reverse resistance in the AML-2/D100 subline in a concentration-dependent manner (Choi et al. 2003). The effect of PTG (100 μg/mL) on drug accumulation of daunorubicin in the AML-2/D100 subline was two-fold higher than that observed in the presence of verapamil (5 μg/mL) and 1.5 times less than cyclosporin A (3 μg/mL). The maximum non-cytotoxic concentrations of PTG did not appear to increase the P-glycoprotein (PgP) levels, which was in contrast to verapamil and cyclosporin A, PTG at 200 μg/mL, or more completely inhibited the azidopine photolabeling of PgP. The results suggested that PTG had a chemosensitising effect on PgP-mediated MDR cells by increasing the intracellular accumulation of drugs through direct interaction with PgP at the azidopine site. In addition, PTG may have a beneficial effect on cancer chemotherapy with respect to the possibility of long-term use without the concern of Pgp activation.

Ginseng ginsenoside Rh_2 inhibited the growth of B16 melanoma cells at the concentration of 10 μg/ml (IC_{50}: 4.1 μg/ml) in-vitro (Xia and Han 1996). Morphologically, ginsenoside Rh_2-induced B16 cells turned out to be epithelioid cells. B16 cells became dendrite shaped morphologically at higher concentration of Rh_2. Flow cytometry demonstrated that the B16 melanoma

cells treated with Rh_2 were blocked at G1 phase. Ginsenoside Rh2 suppressed the growth of human malignant melanoma A375-S2 cells in-vitro by inducing apoptosis (Fei et al. 2002). G-Rh2-induced apoptosis was partially dependent on caspase-8 and caspase-3 pathway in A375-S2 cells. Ota et al. (1987) showed that ginsenosides Rh_1 and Rh_2 controlled the phenotypic expression of mouse B16 melanoma cells in different ways. Rh_2 inhibited the growth of and stimulated melanogenesis in B16 melanoma cells. Rh_2 caused morphological changes of the cells and caused significant increase in cell-to-cell adhesiveness and cell-to-substrate adhesiveness. In contrast, Rh_1, which showed no effect on cell growth, but did stimulate melanogenesis, did not cause morphological changes of the cells and exerted no effect on cell adhesiveness or cell surface lectin binding. Also Rh_1 was not detected in the lipid fraction of B16 melanoma cells. The effects of Rh_2 and protopanaxadiol on B16 melanoma cells were identical, and there was no difference in the lag periods before the appearance of their effects, despite their differing rates of uptake (Ota et al. 1991). Differences in affinity for bovine serum albumin (BSA) and the release rate constants were suggested to be the cause of the difference in uptake kinetics between the compounds.

Although ginseng extract (1 mg/mouse) and ginsenosides Rb_1, Rb_2 and Rc (0.5 mg/mouse) significantly inhibited lung metastasis produced by i.v. injection of B16-BL6 melanoma cells in syngeneic mice (27–61 % of untreated control), they hardly inhibited the invasion and migration of B16-BL6 melanoma and HT1080 fibrosarcoma cells in-vitro (Wakabayashi et al. 1997). In contrast, the intestinal bacterial metabolite M1 formed from ginseng protopanaxadiol saponins inhibited lung metastasis of melanoma cells and in-vitro tumour cell invasion and migration at nontoxic or marginally toxic concentrations. The findings suggested that the in-vivo antimetastatic effect by oral administration of ginsenosides was mediated by their metabolic component M1. Ginsenoside Rh2 suppressed the growth of human malignant melanoma A375-S2 cells in-vitro by inducing apoptosis (Fei et al. 2002). G-Rh2-induced apoptosis was partially dependent on caspase-8 and caspase-3 pathway in A375-S2 cells.

Ginseng ginsenosides Rb_1 and Rb_2 anaerobically incubated with human faecal microflora afforded compound K (IH-901) while ginsenoside Rg_3 was similarly metabolised to ginsenoside Rh_2. All were found to have cytotoxicity activity (Shin et al. 2003). Among ginsenosides, compound K and 20(*S*)-ginsenoside Rh_2 exhibited the most potent cytotoxicity against tumour cells. The cytotoxicity potency of ginsenosides was compound K > 20(*S*)-ginsenoside Rh_2 > ginsenoside Rh_2 > 20(*S*)-ginsenoside Rg_3 > ginsenoside Rb_1 = Rb_2. Treatment of guinea pigs with 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) increased the total cytochrome P450 content 2.86-fold, but this was markedly inhibited by the administration of *Panax ginseng* extracts (Lee et al. 2002a). The administration of TCDD resulted in a 1.73-fold increase in microsomal NADPH-cytochrome P450 reductase activity in the guinea pig liver, and this was significantly inhibited by ginseng extracts. They found that ginseng may act as an inhibitor of cytochrome P450 CYP1A rather than that of CYP2B. Ginsenoside Rh_2 was found to induce apoptosis of human neuroblastoma SK-N-BE(2) cells via activation of caspase-1 and -3 and upregulation of Bax (Kim and Jin 2004).

20-*O*-(β-D-glucopyranosyl)-20(*S*)-protopanaxadiol (IH-901), a novel intestinal bacterial metabolite of ginseng protopanaxadiol saponins, had been reported to induce apoptosis in a variety of cancer cells (Ming et al. 2007). IH-901 inhibited cell growth of human hepatocellular carcinoma SMMC7721 cells in a dose- and time-dependent manner, inducing apoptotic cell death concurrent with cell cycle arrest in G0–G1 phase in SMMC7721 cells. At the molecular level, it was found that IH-901 upregulated cytochrome *c*, p53 and Bax expression and downregulated pro-caspase-3 and pro-caspase-9 expressions in a dose-dependent manner, while the levels of Bcl-2 and Bcl-X_L were unaltered in IH-901-treated SMMC7721 cells. Panaxydol, a ginseng polyacetylene compound, inhibited the proliferation of human hepatocarcinoma cell line

HepG2, induced a cell cycle arrest at the G_1 to S transition and caused morphological and ultrastructural changes in HepG2 cells resembling more mature forms of hepatocytes (Guo et al. 2009). It significantly decreased the secretion of alpha-fetoprotein and the activity of gamma-glutamyl transferase. Panaxydol markedly increased the secretion of albumin and the alkaline phosphatase activity, protein levels of p21 and pRb, and the hypophosphorylated pRb in a dose-dependent manner while reducing mRNA content of Id-1 and Id-2.

3,6,20(*S*)-Trihydroxy-12,23-epoxydammar-24-ene,6,20-di-*O*-β-D-glucopyranoside, isolated from ginseng leaves, showed the moderate cytotoxic activities against human leukemic lymphoma U937 and human cervical cancer HeLa cells (Wang et al. 2008). Korean red ginseng hot aqueous extract treatment to U937 human leukaemia cells resulted in growth inhibition and induction of apoptosis in a concentration-dependent manner (Park et al. 2009b). The increase in apoptosis was associated with the downregulation of antiapoptotic Bcl-2, Bcl-X_L and IAPs family members and the activation of caspase-3. Ginseng polysaccharide (GPS) induced tumouricidal activity against human leukaemia K562, HL-60 or KG1α cancer cells in mouse peritoneal macrophages (Wang et al. 2010d). The treatment enhanced phagocytic activity, NO production and increased the levels of cytokines, including tumour necrosis factor-α (TNF-α), interleukin 1 (IL-1) and interleukin 6 (IL-6). Korean red ginseng extract alone was sufficient to induce granulocytic differentiation accompanied with growth inhibition in acute promyelocytic leukaemia cells (Jo et al. 2013). The results suggested a sequential molecular mechanism from MYC and SKP2 gene expression reduction, Cdkn1b protein stabilisation and G1 phase arrest to granulocytic differentiation by KRGE in acute promyelocytic leukaemia.

Two new polyacetylenes, viz. heptadeca-3-oxo-4,6-diyne-9,10-diol and its dihydro derivative from ginseng callus, exhibited growth inhibition against Yoshida sarcoma cells in tissue culture (Fujimoto and Satoh 1987). A new chlorine-containing polyacetylene and chloropanaxydiol from ginseng callus exhibited growth inhibition against leukaemia cells (L-1210) in tissue culture (Fujimoto and Satoh 1988). Two new polyines, 3-acetyloxy-9,10-epoxy-heptadec-1-en-4,6-diyne (acetylpanaxydol) and 10-chloro-3,9-dihydroxyheptadec-1-en-4,6-diyne (panaxydolchlorohydrin), from Koran ginseng roots exhibited good cytotoxic activity against L1210 cells and were isolated from with ED_{50} values 0.52 μg/ml and 0.50 μg/ml, respectively (Ahn et al. 1989) Panaxyne epoxide (Kim et al. 1989a) and 10-acetyl panaxytriol with ED_{50} of 1.2 μg/ml (Kim et al. 1989b) were cytotoxic against lymphoid leukaemia L1210 cells. Panaxytriol from ginseng showed a growth inhibitory activity against several tumour cell lines: human gastric adenocarcinoma MK-1 cells, mouse melanoma B16 cells, mouse fibroblast-derived tumour L929 cells, human colon adenocarcinoma SW620 cells, human uterus carcinoma HeLa cells and human erythroleukemic K562 cells, with ED_{50} values of 0.8, 1.7, 2.2, 2.3, 10.7 and 11.7 μg/ml, respectively (Matsunaga et al. 1989b). Three polyacetylene compounds, panaxynol, panaxydol and panaxytriol, exhibited in-vitro cytotoxicity activity against several tumour cells (Matsunaga et al. 1990). ED_{50} values of panaxynol, panaxydol and panaxytriol against nude mouse-transplantable human gastric adenocarcinoma MK-1 cells were 0.027, 0.016 and 0.171 μg/ml; against murine melanoma B16 cells 1.23, 1.50 and 2.23 μg/ml; and against human fibroblast-derived tumour L-925 cells 2.50, 2.60 and 4.39 μg/m, respectively. The cell growth inhibitory activity of these compounds was much stronger against malignant cells than against normal cells. Ginseng panaxydol inhibited cell cycle progression of a human malignant melanoma cell line, SK-MEL-1, at G_1-S transition by decreasing cyclin-dependent kinase 2 (Cdk2) activity and upregulating $p27^{KIP1}$ protein expression (Moon et al. 2000).

Ginseng saponin 20-*O*-(β-D-glucopyranosyl)-20(*S*)-protopanaxadiol (IH-901) formed from ginsenosides Rb1, Rb_2 and Rc, exhibited significant, dose- and time-dependent inhibition of proliferation and induction of apoptosis of human myeloid leukaemia cell line HL-60 with

IC_{50} of 24.3 μM (Lee et al. 2000b). Apoptosis was mediated via mitochondrial cytochrome C-mediated activation of caspase-3 protease. Of 16 acetylenic compounds isolated from ginseng roots, panaxydol showed the most potent cytotoxic activity with IC_{50} values of 0.65 μM against Kirsten murine sarcoma virus-transformed NIH/3T3 cells (DT cells), 1.3 μM against NIH/3T3 cells and 0.19 μM against murine lymphoma L1210 cells (Hirakura et al. 2000). Panaxytriol exerted both significant cytotoxicity and inhibition of DNA syntheses in various tumour cells tested in both time- and dose-dependent manner (Kim et al. 2002a). For P388D1, a mouse lymphoma cell line, IC_{50} values for cytotoxicity and inhibition of DNA synthesis were 3.1 and 0.7 μg/ml, respectively. It also induced the cell cycle arrest of P388D1 at the G2/M phase, with corresponding decreases in the proportion of cells at the G0/G1 phase. The S phase also decreased during the 36 hour treatment. Steaming ginseng at high temperature increased its cytotoxicity to SK-Hep-1 hepatoma cancer cells (Park et al. 2002). Ginsenosides Rg3, Rg5, Rk1, Rs5 and Rs4 were found to be the active principles. Their 50 % growth inhibition concentration (GI_{50}) values were 41, 11, 13, 37 and 13 μM, respectively. Cisplatin had a GI_{50} of 84 μM in the same assay conditions.

Ginsenosides derived from 20(*S*)-protopanaxatriol (PT) and 20(*S*)-protopanaxadiol (PD) groups exerted similar characteristic cytotoxic effects on the growth of two intestinal cells lines, Int-407 (HeLa derivative) and Caco-2 (human colon carcinoma) (Popovich and Kitts 2004). Pure Rh_2, a ginsenoside structurally related to PD, inhibited intestinal cell growth at greater than twice the concentration of PD, while Rh_1, a ginsenoside structurally related to aglycone PT, had no cytotoxic effect. Concentrations causing growth inhibition of 50 % of cells (LC_{50}) for the compounds PD, PT and Rh_2 were 23, 26 and 53 μg/mL, respectively, for Int-407 cells. In comparison, the LC_{50} for PD and PT was determined to be 24 μg/mL and that for Rh_2 was 55 μg/mL in Caco-2 cells. Ginsenoside Rh_2 inhibited cell growth by GI arrest at low concentrations and induced apoptosis at high concentrations in a variety of tumour cell lines possibly through activation of caspases (Jia et al. 2004). Rh_2 could act either additively or synergistically with chemotherapy drugs (paclitaxel) on cancer cells. Cheng et al. (2005) found that the antiproliferative effect of Rh2 in human lung adenocarcinoma A549 cells was mediated by G1 growth arrest and apoptosis. The increase in the expression level of TRAIL-RI (DR4) death receptor may play a critical role in the initiation of Rh2-triggered apoptosis, and the activation of the caspase-8/caspase-3 cascade acts as the executioner of the Rh_2-induced death process. Recent studies by Kim et al. (2014c) found that a combination with inhibitor of AMP-activated protein kinase (AMPK) or p38 MAPK (mitogen-activated protein kinase) could augment the anticancer potential of ginsenoside Rh2.

Among the 11 saponins from ginseng fruit, 25-OH-PPD, 20(*S*)-protopanaxadiol and ginsenoside Rh_2 were the most effective inhibitors of cell growth and proliferation and inducers of apoptosis and cell cycle arrest in several human cancer cell lines in-vitro (Wang et al. 2007). For 25-OH-PPD, the IC_{50} values for most cell lines were in the range of 10–60 μM, at least twofold lower than for any of the other compounds. Compounds 25-OH-PPD 20(*S*)-protopanaxadiol had significant, dose-dependent effects on apoptosis, proliferation and cell cycle progression. Dammarane-type sapogenins from ginseng fruit, 20(*R*)-25-methoxyl-dammarane-3β,12β,20-triol and 20(*R*)-20-methoxyl-dammarane-3β,12β,25-triol, showed significant cytotoxic activity against six tumour cell lines (MCF-7, HepG2, Du145, Colon205, A549 and HL-60), and the IC_{50} values of the latter, HepG2, Colon 205, A549 and HL-60, were much lower (Zhao et al. 2011). Panaxydol and panaxyne from wild ginseng roots showed significant and selective cytotoxicity against human SK-OV-3 cancer cells with ED_{50} values 2.93 and 1.40 μM, respectively (Yang et al. 2008).

Floralginsenoside Ta, ginsenoside F_1 and ginsenoside F_5, from ginseng flower buds exhibited cytotoxic activities towards the HL-60 human leukaemia cell line with respective IC_{50} values of

36.3, 23.2 and 62.4 μM (Tung et al. 2010c). Several apoptosis events, including chromatin condensation and increase in the population of sub-G1 hypodiploid cells, were observed in ginsenoside-treated HL-60 human leukaemia cells. Fan et al. (2010) found that ginseng pectin inhibited the migration of murine fibroblast L-929 cells and reduced their migration speed by up to 50 % of control in the presence or absence of serum, suggesting it worked on both serum-dependent and serum-independent migration pathways. Ginseng pectin impaired cell migration via decreased cell spreading. Ginseng leaf ginsenosides Rh_3 and Rk_2 exhibited potent effects against human leukaemia HL-60 cells with IC_{50} values of 0.8 and 0.9 μM (Tung et al. 2010d). In addition, ginsenosides SL_3, (20*S*)-ginsenoside Rg_2, ginsenoside F_4 and (20*S*)-ginsenoside Rh_2 displayed strong activity with IC_{50} values of 9.0, 9.0, 7.5 and 8.2 μM, respectively. Two flavonoids, sophoraflavonoloside and prunin, isolated from the leaves, were found to inhibit the growth in-vitro of human leukaemia HL-60 cells with IC_{50} values of 29.8 and 21.4 μM by induction of apoptosis (Tung et al. 2010b). Polysaccharide (PGPW1) from ginseng root dose dependently displayed potent in-vitro antiproliferation and antimetastatic activities (Li et al. 2012a). PGPW1 could significantly inhibit the proliferation of human bladder T24 cells. PGPW1 had an efficient antimetastatic activity to T24 cells. The binding of ^{3}H-NMS to M3 muscarinic receptors of T24 cells was suppressed by PGPW1. All the data indicated the potential of its clinical application for the prevention and treatment of bladder cancer metastasis. Ginsenoside compound K, a metabolite of the protopanaxadiol-type saponins of *Panax ginseng*, inhibited angiogenesis via inhibition of sphingosine 1-phosphate (S1P) production and sphingosine kinase 1 (SPHK1) activity in human umbilical vein endothelial cells (Shin et al. 2014b). Expression of the pro-apoptotic sphingolipids, sphingosine and ceramide was increased in response to ginsenoside K. Ginsengenin, isolated from *P. ginseng*, exhibited in-vitro cytotoxicity against human colorectal carcinoma SW1116, human colon cancer HCT116 and human lung cancer A549 cells with IC_{50} values in the range of 2.96–30.9 μmol/L (Guan et al. 2013). Three derivatives synthesised from 25-hydroxyprotopanaxadiol from ginseng root, namely, (20R)-12*β*-*O*-(L-chloracetyl)-dammarane-3*β*, 20, 25-triol; (20R)-3β-*O*-(L-alanyl)-dammarane-12*β*, 20, 25-triol; and (20R)-3*β*-*O*-(Boc-L-arginyl)-dammarane-12*β*, 20, 25-triol, significantly inhibited the growths of human colorectal HCT116 cancer cells by induction of apoptosis via caspase-signalling pathways activation (Xia et al. 2014). 20(S)-Protopanaxadiol, a metabolite of ginseng, exerted potent anticarcinogenic effects on colon carcinogenesis by increasing Ca^{2+} influx, mainly through transient receptor potential canonical (TRPC) channels and by targeting AMP-activated protein kinase (Hwang et al. 2013a).

Gintonin from ginseng and LPA C18:2 inhibited ATX activity and metastasis-related cellular activities in melanoma cells (Hwang et al. 2013b). Ginseng-derived gintonin (containing 9.5 % lysophosphatidic acid (LPA), mainly LPA C18:2) and LPA C18:2 inhibited the purified and secreted autotaxin activity from B16/F10 melanoma cells in a concentration-dependent manner. Gintonin also inhibited cell migration with a minimal inhibition of cell growth. The oral administration of gintonin or LPA C18:2 inhibited lung metastasis induced by tail-vein inoculations of melanoma cells. Moreover, the oral administration of gintonin significantly suppressed the tumour growth induced by subcutaneous grafts of melanoma cells. Also oral administration of gintonin reduced tumour necrosis, the pleomorphism of tumour cells and tumour cell mitosis and angiogenesis. The study demonstrated that the gintonin-induced inhibition of activity may be the molecular basis of ginseng-induced antimetastatic and antitumour activities. Ginseng root polysaccharide (PGP2a) exhibited potent inhibitory effect on the growth of human gastric cancer HGC-27 cells in a dose-dependent fashion (Li et al. 2014). It caused apoptosis and growth cycle arrest in the G2/M phase in HGC-27 cells. Protein expressions of Twist and AKR1C2 were suppressed by PGP2a, whereas an increase of NF1 was observed at protein level. Ginseng root polysaccharide dose dependently decreased migration

and invasion of HGC-27 cells by regulation of Twist, AKR1C2, NF1, E-cadherin, vimentin and N-cadherin expression (Cai et al. 2013). Ginsenosides Re and Rg_1 inhibited ubiquitin-activating enzyme (EI), but ginsenosides Re and Rg1 and ginsenosides Rb_1, Rb_2, Rc and Rd increased ubiquitination on E1 enzyme (Chang et al. 2014). Moreover, ginsenoside Rg_1 inhibited both the chymotrypsin-like activity of 26S proteasome and E1 activity suggesting ginsenoside Rg_1 to be a potential functional food application for cancer prevention because of its specific E1 inhibitory effects.

Animal Studies

Oral administration of ginsenoside Rh_2 (Rh_2) inhibited tumour growth in nude mice bearing human ovarian cancer cells (Tode et al. 1993a, b). In particular, tumour growth in mice treated with 15, 30 and 120 μM Rh_2 was significantly inhibited compared to that in cisplatin (CDDP)-treated mice as well as in untreated mice. Consequently, 50 % survival in nude mice treated with 15, 30 and 120 μM Rh_2 was significantly prolonged compared to that not only in untreated mice but also in CDDP-treated mice. Multiple administrations of ginseng ginsenoside Rb_2, after the intravenous inoculation of B16-BL6 melanoma cells in syngeneic mice, resulted in a significant inhibition of lung metastasis as compared with the untreated control (Sato et al. 1994). The results suggested that the inhibition of tumour-associated angiogenesis by ginsenoside Rb_2 may partly contribute to the inhibition of lung tumour metastasis. Further, they found that both ginseng saponins, 20(*R*)- and 20(*S*)-ginsenoside Rg_3, possessed an ability to inhibit the lung metastasis of tumour cells of B16-BL6 melanoma and lung metastasis produced by colon 26-M3.1 carcinoma in syngeneic mice (Mochizuki et al. 1995). The mechanism of their antimetastatic effect was related to inhibition of the adhesion and invasion of tumour cells and also to anti-angiogenesis activity.

Ginsenoside Rh_2 (Rh_2), isolated from an ethanol ginseng extract, inhibited proliferations of various established human ovarian cancer cell lines in a dose-dependent manner between 10 and 60 μM in-vitro and induced apoptosis at around the IC_{50} dose (Nakata et al. 1998). Although i.p. administration of Rh_2 alone to mice with ovarian cancer cells hardly inhibited tumour growth, when Rh_2 was combined with *cis*-diamminedichloroplatinum (II) (CDDP), the tumour growth was significantly inhibited, compared to treatment with CDDP alone. When mice were treated p.o. with Rh_2 daily (but not weekly), the tumour growth was significantly inhibited, compared to CDDP treatment alone. When Rh_2 was combined with CDDP, the degree of tumour growth retardation was not potentiated. It was found that p.o. but not i.p. treatment with Rh_2 resulted in the induction of apoptotic cells in the tumour in addition to augmentation of the natural killer activity in spleen cells from tumour-bearing nude mice. Panaxytriol (40 mg/kg) administered intramuscularly produced significant tumour growth delays of B16 melanomas in C57BL/6 mice (Katano et al. 1990).

Red ginseng extracts at 50–400 mg/kg inhibited DMBA/croton oil-induced skin papilloma in mice, decreased the incidence of papilloma, prolonged the latent period of tumour occurrence and reduced tumour number per mouse in a dose-dependent manner (Chen et al. 1998). Red ginseng extract B effectively inhibited the Fe^{2+}/cysteine-induced lipid peroxidation of rat liver microsome, suggesting that red ginseng extract B had a stronger antioxidative effect than that of extract A. The results indicated that red ginseng extracts (50–400 mg/kg) could significantly inhibit the growth of transplantable mouse sarcoma S180 and melanoma B16. Red ginseng extracts A (0.5 mg/ml) and B (0.1 and 0.25 mg/ml) could effectively promote the transformation of T lymphocyte, but there was no influence on lymphocyte proliferation stimulated by concanavalin A. The results suggested that red ginseng extracts had potent tumour therapeutic activity and improved the cell immune system. Use of red ginseng extract elicited 22 % decrease in the incidence of urethane-induced lung adenoma in mice (Yun et al. 2001a). In mice sacrificed at 56 weeks after the treatment with aflatoxin B1, the incidence of hepatoma significantly decreased to 75 % by the addition of red ginseng extract. In

lung tumour models in mice, significant anticarcinogenic effects of powders and extracts of the 6-year-old dried fresh ginseng, 5- and 6-year-old white ginsengs and 4-, 5- and 6-year-old red ginseng were confirmed. The anticarcinogencity of ginseng was enhanced in aged or heat-treated extracts of ginseng and red ginseng made by steaming. Among the semisynthetic ginsenosides tested, Rg_3 and Rg_5 showed statistically significant reduction of lung tumour incidence, and Rh_2 had a tendency of decreasing the incidence. Ginsenoside Rg_3, Rg_5 and Rh_2 were found to be active anticarcinogenic compounds.

Topical application of methanol extract of heat-processed neo-ginseng (designated as "NGMe") onto shaven backs of female ICR mice 10 minute prior to 12-*O*-tetradecanoylphorbol-13-acetate (TPA) significantly ameliorated skin papillomagenesis initiated by 7,12-dimethylbenz[*a*]anthracene (Keum et al. 2001). Moreover, TPA-induced enhancement of epidermal ornithine decarboxylase (ODC) activity and ODC mRNA expression was abolished by a topical dose (0.68 mg) of NGMe. Likewise, TPA-induced production of tumour necrosis factor in mouse skin was inhibited by NGMe pretreatment. Studies suggested that the antitumour promoting activity of ginsenoside Rg_3 may possibly be mediated through downregulation of NF-κB and AP-1 transcription factors (Keum et al. 2003). Pretreatment of dorsal skins of female ICR mice with Rg_3 significantly inhibited 12-*O*-tetradecanoylphorbol-13-acetate (TPA)-induced ornithine decarboxylase activity and 7,12-dimethylbenz[*a*]anthracene-initiated papilloma formation. In another experiment, Rg_3 pretreatment abrogated the expression of cyclooxygenase-2 in TPA-stimulated mouse skin. Rg_3 also inhibited the TPA-induced activation of the eukaryotic transcription factor, NF-κB, in both mouse skin and cultured human pro-myelocytic leukaemia (HL-60) cells. Also, Rg_3 exerted potent inhibitory effects on the activation of another transcription factor, activator protein-1 (AP-1), that is responsible for c-*jun* and c-*fos* oncogenic transactivation.

The oral administration of *Panax Ginseng* extract (EFLA400, processed *Panax ginseng* extract containing a high titre of ginsenoside Rg3 (>3.0 % w/w) known as Phoenix ginseng) at 1, 3 and 10 mg/kg body weight at pre-, peri- and post-initiational phases showed significant reductions in the number, size and weight of the papillomas in Swiss albino mice (Panwar et al. 2005a). A significant reduction in tumour incidence (71.41 %, 72.19 % and 70.46 % at 1, 3 and 10 mg/kg body weight, respectively) was observed in animals in the EFLA400-treated group compared with 100 % tumour incidence in the control group. The average tumour weight was recorded as 128.55, 116.00 and 57.5 mg in 1, 3 and 10 mg/kg body weight EFLA400-treated groups, respectively. In the EFLA400-treated groups, significantly reduced frequencies of chromosomal aberrations and micronuclei induced by DMBA and croton oil were observed. However, the maximum decrease in the frequencies of chromosomal aberrations and micronuclei was recorded in the 10 mg/kg body weight EFLA400-treated group than that of the 1 and 3 mg/kg body weight EFLA400-treated animals. They also demonstrated that oral administration of EFLA400 (10 mg/kg body weight) showed significant reduction in number of adenomas and weight of the lungs induced by benzo(a)pyrene (BP) in newborn Swiss albino mice (Panwar et al. 2005b). A significant reduction in lung adenoma incidence in EFLA400-treated mice was observed as compared to the 68.3 % lung adenoma incidence in BP-alone group. In EFLA400-treated group, significantly reduced frequencies of chromosomal aberrations and micronuclei induced by BP were observed.

In-vitro and in-vivo studies demonstrated that two novel ginsenosides, 25-OH-PPD (20(R)-dammarane-3β,12β,20,25-tetrol) from *P. ginseng* and 25-OCH_3-PPD (20(S)-25-methoxyl-dammarane-3β,12β,20-triol) from *P. notoginseng*, inhibited proliferation, caused cell cycle arrest and induced apoptosis in human pancreatic cells and also both inhibited the growth of Panc-1 xenograft tumours without any host toxicity (Wang et al. 2009b). Preliminary investigations suggested that their effects may be partially mediated by their inhibition of the murine double minute (MDM2) oncogene and related pathways.

Kim et al. (2013c) found that *Panax ginseng* extract exerted antiproliferative effects on rat hepatocarcinogenesis by induction of cell cycle arrest but not extracts of *Panax japonicus* or *P. quinquefolius*. Ginseng diet downregulated the expression of Cyclin D1, Cyclin G1, Cdc2a *and* Igf-1, which were involved in the p53 signalling pathway. Treatment of rats with ginseng extract during, before or after the treatment with aflatoxin B1 and fumonisin improved all biochemical parameters and histological picture of the liver (Abdel-Wahab et al. 2010). Moreover, treatment with ginseng extract after the administration of the mycotoxins was found to be more effective. It was concluded that ginseng had protective effects as precancerous lesions and therapeutic effects as well.

Antimutagenic/Antigenotoxic Activity

Total saponins from ginseng stem and leaf (TSPG) significantly reduced the genotoxicity of cyclophosphamide in bone marrow cells and peripheral lymphocyte cells and decreased the apoptotic cell number induced by cyclophosphamide in bone marrow cells (Zhang et al. 2008b). TSPG antagonised cyclophosphamide-induced reduction of T-SOD, GPx, CAT activities and the GSH contents.

Panax ginseng extract standardised with ginsenoside Rg_3 (ginsenoside Rg_3 content was 3.6 % w/w, i.e. 36 μg/mg *P. ginseng* extract) was found to have a protective effect against ethylenediaminetetraacetic acid (EDTA)-induced biochemical, genotoxic and histological changes in rats (Khalil et al. 2008). EDTA is widely used in food and other industries to sequester metal ions and to prevent their disadvantageous effects. EDTA administration to rats caused a significant decrease in the serum biochemical parameters and antioxidant enzymes activity, increased lipid peroxidation and the incidence of micronucleated polychromatic erythrocytes (MnPCEs), caused appearance of some changes in polymorphism band patterns and induced different histopathological lesions in the livers, kidneys and testis. Treatment with *P. ginseng*, garlic alone or plus EDTA significantly improved all the tested parameters. Furthermore, *P. ginseng* extract was found to be more effective than garlic in restoring the parameters that were altered by EDTA.

Antiplatelet/Antithrombotic Activities

A 70 % methanol extract of Korean red ginseng prevented the exchanges of values of clinical examination (blood platelet, fibrinogen and prothrombin time) at a dose of 500 mg/kg in rats on disseminated intravascular coagulation (DIC) induced by endotoxin or thrombin (Matsuda and Kubo 1983). The extract exhibited fibrinolytic activity in rats in the fibrinolytic system. In the in-vitro experiments, incubation of the extract in the plasminogen-containing fibrin plate promoted activation of urokinase action. Ginsenoside Ro (50 mg/kg, p.o.) prevented the decrease of fibrinogen in endotoxin-induced models of disseminated intravascular coagulation (DIC) in rats (Matsuda et al. 1986b). Ginsenoside Ro also inhibited the formation of fibrin thrombin in the renal glomeruli in thrombin-induced DIC. Ginsenoside Ro showed a promotive effect on the activation of the fibrinolytic system. Ginsenoside Rg_2 also showed strong inhibitory activity on platelet aggregation induced by three aggregating agents (endotoxin, collagen and arachidonic acid) as compared with aspirin at a concentration of 1.0 mM (Matsuda et al. 1986a). Ginsenoside Ro inhibited the conversion of fibrinogen to fibrin induced by thrombin at concentrations of 0.1–1.0 mM. Ginsenosides Ro, Rb_1, Rb_2, Rc, Re, Rg_1 and Rg_2 may promote the action of urokinase in the fibrinolytic system on the basis of its action on plasminogen-containing fibrin plates. Ginseng ginsenoside Rb_2 enhanced fibrinolytic activity of bovine aortic endothelial cells (BAEC) (Liu et al. 2003). Ginsenoside Rb_2 enhanced the plasminogen activator activity levels as well as the surface plasmin activity in BAEC. Rb_2 stimulated the secretion of urokinase-type PA (uPA) without enhancing the gene expression of uPA, uPA receptor (uPAR) and/or its inhibitor PAI-1.

The non-saponin fraction (NSF; lipophilic fraction) from ginseng roots dose dependently inhibited the aggregation of human platelets induced by thrombin and inhibited Ca^{2+}-influx into platelets (Park et al. 1995). NSF induced the elevation of cGMP concentration in human platelets in a similar manner to molsidomine, a known vasodilator, and potently inhibited the thromboxane A_2 (TXA_2) production. The results suggested that NSF may regulate the levels of cGMP and TXA_2 to inhibit platelet aggregation induced by thrombin.

Panaxynol was found to be the most potent antiplatelet agent in ginseng, and its mechanism of action was primarily attributed to the inhibition of thromboxane formation (Teng et al. 1989). Panaxynol (0.1 mg/ml) inhibited markedly the aggregation of washed platelets induced by collagen, arachidonic acid, ADP, ionophore A23187 and PAF. Ginsenosides had no significant effect on the aggregation, but ginsenoside Ro (1 mg/ml) inhibited the ATP release of platelets. Thromboxane B_2 formation of platelets was inhibited by panaxynol but not by ginsenosides. 20(*S*)-Ginsenoside and delta20-ginsenoside Rg_3 and protopanaxadiol-type saponins from ginseng were found to be relatively potent platelet activating factor antagonists ($IC_{50} = 4.9 \times 10^{-5}$ M and 9.2×10^{-5} M, respectively) (Jung et al. 1998). Total saponin from Korean red ginseng extract was found to be a beneficial herbal substance elevating cAMP level in thrombin–platelet interaction, which may result in the prevention of platelet aggregation-mediated thrombotic diseases (Lee et al. 2013b). The extract dose-dependently inhibited thrombin-induced platelet aggregation with IC_{50} value of 81.1 μg/mL, decreased the level of cytosolic-free Ca^{2+} and inhibited thrombin-elevated adenosine triphosphate (ATP) release from platelets. The extract significantly dose-dependently elevated intracellular level of cAMP.

Studies by Park et al. (1996) found that the lipophilic fraction (LF) from *Panax ginseng* increased cGMP directly and cAMP indirectly and thus inhibited thrombin- or collagen-induced rat platelet aggregation. Both the thrombin time (TT) and activated partial thromboplastin time (APTT) were prolonged more in citrated platelet-poor plasma from 15 % corn oil plus LF-administered rats (COLF) than that from 15 % corn oil only-administered rats (CO). The level of lipids such as triglyceride, total cholesterol, high-density lipoprotein cholesterol and low-density lipoprotein cholesterol was decreased in serum from COLF more than in that of CO. Kim et al. (1999a) isolated antithrombin active heteropolysaccharide from red ginseng; it inhibited blood coagulation via the intrinsic pathway like heparin in a dose-dependent manner. The clotting of fibrinogen by thrombin was also mitigated by the presence of this polysaccharide. In rats with blood stasis induced by high molecular weight dextran, Korean red ginseng (KRG) and its herbal prescription (KRGP) consisting of five herbs such as Korean red ginseng, *Ganoderma*, *Cinnamomi cortex*, *Glycyrrhizae radix* and *Laminaria* not only significantly restored the number of platelets and fibrinogen but also suppressed the fibrin degradation products (FDP) to normal range (Yun et al. 2001b). In platelet aggregation assay with human platelet-rich plasma (PRP), KRG and KRGP significantly inhibited thrombin- and collagen-induced platelet aggregation. In coagulation assay, KRG and KRGP significantly prolonged activated partial prothrombin time (APPT) and prothrombin time (PT) as compared with control data. KRGP was found to be more effective than KRG alone on antithrombotic activity.

Administration of Korean red ginseng (KRG) to rats not only prevented carotid artery thrombosis in-vivo in a dose-dependent manner but also significantly inhibited ADP- and collagen-induced platelet aggregation ex vivo while failing to prolong coagulation times such as activated partial APTT and PT, indicating that the antithrombotic effect of KRG might be due to its antiplatelet aggregation rather than anticoagulation effect (Yu et al. 2006; Jin et al. 2007). KRG inhibited U46619-, arachidonic acid-, collagen- and thrombin-induced rabbit platelet aggregation in-vitro in a concentration-dependent manner, with IC50 values of 620, 823, 722 and 650 μg/mL, respectively. Accordingly, KRG also inhibited various agonists-induced platelet

serotonin secretions as it suppressed platelet aggregation. Thus, KRG intake may be beneficial to the individuals with high risks of thrombotic and cardiovascular diseases. Administration of Korean red ginseng water extract (KRG-WE) (200 mg/kg/day) to high-cholesterol-diet-fed rabbits for 8 weeks potently inhibited the platelet aggregation induced by low doses of agonists (0.5 μg/mL collagen and 0.025 unit/mL thrombin), whereas it weakly reduced the blood cholesterol levels and formation of atheromatous lesions (Hwang et al. 2008). Further, KRG-WE significantly suppressed collagen-induced 1,2-diacylglycerol liberation but had no significant effect on arachidonic acid liberation. The results suggested that the antiplatelet effect of KRG-WE may, at least partly, be due to the inhibition of 1,2-diacylglycerol generation rather than regulation of blood lipid levels. In a screening of various fractions of Korean red ginseng, Wee et al. (2010) found that the ethyl acetate fraction possessed potent anticoagulant activity in-vitro, and phenolic acids vanillic, caffeic, ferulic and p-coumaric were identified as the active components in this fraction. Ginsenosides Rg_6, F_4 and Rk_3 from processed ginseng showed inhibitory activity (IC_{50} = 76 μM, 114 μM and 128 μM, respectively) on arachidonic acid-induced platelet aggregation (Lee et al. 2010a). The corresponding IC_{50} values were comparable to that of acetylsalicylic acid (ASA) (63 μM). Compared to ASA (IC_{50} = 468 μM), ginsenosides Rg_6, F_4, Rk_3 and Rh_4 were found to be more inhibitive (IC_{50} = 286 μM, 87 μM, 187 μM and 119 μM, respectively) against U46619 (thromboxane A_2 mimetic drug)-induced aggregation. In contrast, most of the ginsenosides (Rg_6, F_4, Rh_4, Rs_3, Rs_5) showed negligible effects on adenosine diphosphate- and collagen-induced platelet aggregation. The acetylated ginsenosides (Rs_3, Rs_4 and Rs_5) had only mild effects on aggregation induced by the four stimulators. Rg_1 significantly inhibited platelet aggregation induced by thrombin, ADP, collagen and U46619 via the inhibition of ERK phosphorylation and attenuated arterial thrombus formation in-vivo (Zhou et al. 2014). Rg_1 also reduced thrombin-enhanced fibrinogen binding and P-selectin expression of single platelet and decreased the rate of clot retraction in platelet-rich plasma. Rg_1 was found to prolong the mesenteric arterial occlusion time.

Ergogenic (Antifatigue)/Adaptogenic Activity

Ginseng had been used by athletes as an ergogenic aid for many years despite the lack of compelling research evidence in support of its use for this purpose (Bahrke and Morgan 1994). Ginseng root had been considered a tonic or adaptogenic that enhanced physical performance (including sexual), promoted vitality and increased resistance to stress and ageing (Nocerino et al. 2000). The adaptogenic properties of ginseng were believed to be due to its effects on hypothalamic–pituitary–adrenal axis, resulting in elevated plasma corticotropin and corticosteroids levels. When used appropriately, ginseng appeared to be safe.

Animal Studies

All ginseng saponins showed antifatigue action (Kaku et al. 1975). They markedly increased the movement after compulsory gait, and the action was consistent and independent of their action on the movement before compulsory gait. Ginseng water extract significantly accelerated the recovery of exploratory movements in mice, increased motor activity index in exploratory movement (EM) and elevated rectal temperature (RT) test (Saito et al. 1974). However, water extract decreased the index in hole cross (HC) and grip tone in spring balance (SB) test. An in-vivo study showed that administration of ginseng did not significantly alter the lifespan of mice, but it did cause an exaggeration of the behavioural responses to mild stress (Bitties et al. 1979). This effect was noticeable soon after ginseng administration and subsequently was maintained. Banerjee and Izquierdo (1982) found both piracetam and ginseng treatment provided good protection against electroshock stress when compared to the untreated mice; fighting scores, incidence of tonic convulsion and mortality were significantly less in

the treated groups. In the heat stress experiments, both piracetam and ginseng provided significant protection to the treated mice against exposure to heat. In the fatigue stress of forced swim test, ginseng treatment provided effective adaptation to fatigue and increased endurance in both male and female mice; piracetam showed some antifatigue effects on the male mice only. In the locomotor activity tests, ginseng did not depress motility, while piracetam did so in the later part of the tests. Avakian et al. (1984) found that during exercise, ginseng extract-treated rats had higher blood glucose levels than control rats and markedly lower concentrations of circulating lactic acid, pyruvic acid and free fatty acid levels. The data suggested that ginseng ginsenosides could significantly alter mechanisms of fuel homeostasis during prolonged exercise, presumably by increasing the biochemical capacity of skeleton muscle to oxidise free fatty acids in preference of glucose for cellular energy production. In an earlier animal study, they found that ginseng extract had pronounced inhibitory effects on endogenous glycogen utilisation in white skeletal muscle during exercise (Avakian and Evonuk 1979). The findings indicated that ginseng extract had carbohydrate-sparing actions during prolonged exercise and suggested a possible physiological basis for ginseng's antifatigue properties.

Lasarova et al. (1987) found that standardised ginseng extract, administered in a dose of 30 mg/kg orally for 10 days prior to the beginning of the training session, markedly tended to eliminate the memory-impairing effect of electroconvulsive shock in rats. *Panax ginseng* root and *Ginkgo biloba* leaf extracts exhibited positive endurance-promoting properties of rats using both cold-hypoxia-restraint model and cold swimming models (Ramachandran et al. 1990). The cold-hypoxia-restraint model was found to provide more precise results compared with the cold-swimming model. In contrast, studies by Lewis et al. (1983) found no significant difference in stamina or longevity between mice drinking infusions of two preparations of Siberian ginseng, Oriental ginseng or American ginseng and control mice when subjected to swimming trials in cold water 38, 46 and 96 days after treatment began. Consequently, ingestion of adaptogenic glycosides did not significantly affect the survival of mice under major environmental stress.

Antifatigue effects of ginsenoside Rg_1 were obvious in every test. Lipophilic fraction significantly speeded up recovery from fatigue in EM, rotating rod (RR), RT and SB tests but delayed recovery in HC and sliding angle (SA) tests. In separate studies, ginseng extract (GNo. 3), ginseng lipophilic fraction (GNo. 5) and ginsenoside Rg1, at small consecutive doses, expedited recovery from exhaustion in mice after 4 hour oscillation period (Takagi et al. 1974). Ginsenoside Rg was found to stimulate the central nervous system, while ginsenoside Rb exerted a sedative effect. Administration of ginseng and its ginsenosides to mice before but not after ethanol treatment was found to enhance exercise endurance and reduce the plasma level of ethanol (Koo 1998). Gastric emptying was slowed by ginseng, ginsenosides or ethanol administration. An additive effect was observed when the mice were pretreated with ginseng or ginsenosides 10 minutes before ethanol administration.

Administration of *Panax ginseng* extract G115 significantly increased hepatic glutathione peroxidase activity (GPX) and reduced glutathione (GSH) levels in the liver, with a dose-dependent reduction of the thiobarbituric acid reactive substances (TBARS) (Voces et al. 1999). After the exercise, there was reduced hepatic lipid peroxidation, as evidenced by the TBARS levels in both the control and treated animals. The GPX (glutathione peroxidase) and SOD (superoxide dismutase) activities were also significantly increased in the groups receiving G115, compared with the controls. The hepatic transaminase levels, ALT (alanine aminotransferase) and AST (aspartate aminotransferase), in the recuperation phase 48 hours after the exercise indicated a clear hepatoprotective effect related to the administration of the standardised ginseng extract G115. At hepatic level, G115 increased the antioxidant capacity, with a marked reduction of the effects of the oxidative stress induced by the exhaustive exercise. Oral administration of red ginseng for 30 days resulted in improvement of Cornell Medical Index (CMI) and the State–Trait Anxiety Inventory (STAI)

psychological scores in postmenopausal women suffering climacteric syndromes, particularly fatigue, insomnia and depression (Tode et al. 1999). The ameliorating effect of red ginseng was in part attributed to its effects on stress-related hormones as shown by a decrease in cortisol/dehydroepiandrosterone-S ratio. Intraperitoneal administration of a bioactive water-soluble saponin-free fraction (RG-ws-l-l-l) from red ginseng (200 mg/kg, 14 days) to mice resulted in an increase in oxygen consumption at 37 °C (Larina et al. 2001). Oxygen consumption and formation of superoxide radicals (FSR) by neutrophils were suppressed when cells obtained from the control animals were incubated at 42 °C. Preincubation of neutrophils with RG-ws-l-I-1 reduced heat stress-related depression of FSR. In-vivo administration of RG-ws-I-l-1 to mice decreased heat stress-related suppression of oxygen consumption. Thus, RG-ws-1-1-1 subfraction significantly improved an oxygen-dependent antimicrobial function of neutrophils under heat stress.

Ginseng total saponins, ginsenosides Rb_2, Rg_1 and Rd, administered intraperitoneally attenuated the immobilisation stress-induced increase in plasma interleukin IL-6 level in mice (Kim et al. 2003a). Results suggested that the inhibitory action of ginseng saponins against the immobilisation stress-induced increase of plasma IL-6 level would be in periphery, at least in part mediated by blocking norepinephrine- and/or epinephrine-induced increase of IL-6 level in macrophage rather than in the brain. Lee et al. (2006c) reported that administration of total saponins (GTS), ginsenosides Rg_3 and Rb_1, led to an antistress effect in immobilisation-stressed gerbil mice. Pretreatment of GTS and ginsenosides Rg_3 and Rb_1 reduced the stress-elevated polyamine putrescine level in the brain. Voces et al. (2004) showed that oral administration of ginseng extract for 3 months to male Wistar rats was able to protect muscle from exercise-induced oxidative stress irrespective of fibre type. Lipid peroxidation, measured on the basis of malondialdehyde levels, was significantly higher in all muscles after exercise and again was reduced by about 74 % by the use of ginseng extract. The results showed a membrane-stabilising capacity of the extract since mitochondrial function measured on the basis of citrate synthase and 3-hydroxyacyl-CoA dehydrogenase activities was reduced, on average, by 20 % after exercise, but the activities remained unchanged in animals treated with a ginseng dose of 100 mg/kg. Pannacci et al. (2006) found that administration of ginseng G115 to mice enhanced the production of proinflammatory cytokine linked to an increased expression of toll-like receptor 4 (TLR4) RNA in peritoneal macrophages during swimming stress. A significant increase of lipopolysaccharide (LPS)-stimulated interleukin IL-1beta and TNF-α concentrations was present in trained animals with similar patterns of TLR4 expression. A crude extract and a standardised ginseng extract (G115) of different saponin compositions appeared to be equally effective in reducing injuries and inflammation caused by eccentric muscle contractions in rats (Cabral de Oliveira et al. 2001). Both extracts reduced lipid peroxidation by approximately 15 % as measured by malondialdehyde levels. β-Glucuronidase concentrations and glucose-6-phosphate dehydrogenase (G6PDH) levels, which can be considered markers of inflammation, were also significantly reduced. Ginseng treatment (100 mg/kg) protected muscles from eccentric exercise injuries (Cabral de Oliveira et al. 2005). It was effective in preserving mitochondrial membrane integrity and reduced nitrate concentration in vastus and rectus (46 % and 26 %, respectively). It also reduced carbonyl contents by approximately 27 % in all the muscles studied. Animal studies demonstrated that ginseng ginsenoside Rg_3 mimicked improved cardiac adaptations to exercise by regulating mitochondrial dynamic remodelling and enhancing the quantity and quality of mitochondria (Sun et al. 2013). Both aerobic exercise training and Rg_3 supplementation enhanced peroxisome proliferator-activated receptor coactivator 1 alpha (PGC-1α) and nuclear factor-E2-related factor 2 (Nrf2) protein levels in the rat cardiac muscle. Red ginseng appeared to inhibit oxidative stress-inducible peptidyl arginine deiminase type 4 (PADI4) by upregulating oestrogen receptor (ER)-β expression in the brain of immobilisation-

stressed mice, thus protecting brain cells from apoptosis (Kim et al. 2013a).

Clinical Studies

The water extract of *Panax ginseng* had a preventative action against somatic fatigue in the human body, associated probably to its central stimulant action (Yamada 1955). In a study on the effects of ginseng in fatigued night nurses, nurses assessed night duty as impairing performance in all mood scales and most of the bodily feeling scales; ginseng improved the self-rating scales for competence, mood and performance in one of the psychophysical tests (Hallstrom et al. 1982). Compared to placebo, ginseng had no effect on the blood tests. A double-blind, randomised, crossover study in 50 healthy male sports teachers aged 21–47 years, found that the six-week administration of ginseng preparation containing ginseng extract, dimethylaminoethanol bitartrate, vitamins, minerals and trace elements, increased the subjects' work capacity by improving muscular oxygen utilisation compared to placebo (Pieralisi et al. 1991). In a study of seven healthy male subjects, administration of ginseng extract significantly increased exercise duration on the treadmill until exhaustion by 1.5 minutes (Kim et al. 2005). It was found that the elevation in catalase and superoxide dismutase activities as scavenger enzymes after ginseng extract administration resulted in the decrease of malondialdehyde level and consequently prolonged exercise duration until exhaustion. The findings supported scientific claims that ginseng had ergogenic properties in facilitating recovery from exhaustive exercise. Ginseng polysaccharides were found to have antifatigue activity, also reflected in the effects on the physiological markers for fatigue (Wang et al. 2010c). Ginseng polysaccharides (WGP) and its fractions neutral (WGPN) and acidic (WGPA) inhibited forced swim test-induced reduction in glucose and glutathione peroxidase and increase in creatine phosphokinase, lactic dehydrogenase and malondialdehyde levels, all indicators of fatigue. The acidic polysaccharide was more potent than the neutral polysaccharide. In a subsequent paper, they reported that oral administration of ginseng acidic polysaccharide WGPA and its active fraction WGPA-A prolonged swimming time of mice in the forced swimming test (Wang et al. 2014a). Malondialdehyde and lactate dehydrogenase levels in the serum were enhanced, while those of superoxide dismutase and glutathione peroxidase were lowered. Also, the structural degeneration of mitochondria was ameliorated. The results suggested that WGPA-A may have potential therapeutic effects for chronic fatigue syndrome and that oxidative stress may be involved in the disorder.

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increase lipolysis, ease heart rate, reduce plasma lactate concentration and maintain good health.

Anti-allergic Activity

Among ginsenoside Rc and its metabolites, compound K exhibited the most potent anti-allergic activity on the IgE-induced RBL-2H3 basophilic leukaemia cell line as well as potent cytotoxic activity against L1210 (mouse lymphocytic leukaemia cell line), P388 (mouse lymphoid neoplasm cell line) and A549(human lung carcinoma) cell lines (Bae et al. 2002a). Compound K and Rh_2 metabolites from ginseng ginsenosides exhibited the most potent inhibitory activity on beta-hexosaminidase release from RBL-2H3 cells and on the passive cutaneous anaphylaxis reaction (PCA) reaction (Choo et al. 2003; Park et al. 2003). The inhibitory activity of both compounds was more potent than that of disodium cromoglycate, one of the commercial anti-allergic drugs. The anti-allergic action of compound K and ginsenoside Rh_2 emanated from its cell membrane-stabilising activity. Also, the ginsenosides of ginseng were found to be prodrugs with extensive anti-allergic properties. Ginseng ginsenoside Rh_1 potently inhibited histamine release from rat peritoneal mast cells and the IgE-mediated PCA in mice (Park et al. 2004a). Its inhibitory action on PCA reaction was more potent than that of disodium cromoglycate. Rh_1 was also found to have a membrane-stabilising action and also inhibited inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2) protein expression in RAW 264.7 cells and the activation of the transcription factor, NF-κB, in nuclear fractions. Studies suggested that red ginseng inhibited allergic reactions to food by preventing reductions in the ratio of interferon IFN-γ to interleukin IL-4 and in IL-12 production induced by dietary antigens in spleen cells and/or increasing the expression of CD8 and IFN-γ in the small intestine (Sumiyoshi et al. 2010). It was concluded that red ginseng roots may be a natural preventative of food allergies.

Ginsenoside Rh_1 and compound K purified from fermented ginseng exhibited anti-allergic effects in compound 48/80-induced anaphylactic shock model in mice (Kim et al. 2008a). Ginsenoside RH1 exerted better anti-allergic effects than compound K. The results suggested that fermented ginseng extracts with enriched Rh_1 may be utilised as a potential biomaterial of functional food for the alleviation of allergic symptoms.

Panax ginseng treatment restored the expression of eosinophil major basic protein (EMBP), mucin 5AC glycoprotein (Muc5ac), CD40 and CD40 ligand (CD40L), as well as the mRNA and protein levels of interleukin (IL)-1β, IL-4 and IL-5 and tumour necrosis factor (TNF)-α in lung tissues (Kim and Yang 2011). Additionally, ginseng inhibited the numbers of goblet cells, and further, small G proteins and MAP kinases in bronchoalveolar lavage cells and lung tissues increased in ovalbumin-induced allergic asthma in mice. The results suggested that ginseng may be used as a therapeutic agent in asthma, based on reductions of various allergic responses. Both red ginseng (RG) and fermented red ginseng (FRG) decreased serum IgE, OVA-IgE and proinflammatory cytokines in ovalbumin-sensitised female BALB/c mice (Lee et al. 2012a). Serum β-lactoglobulin, a marker of gut permeability, was significantly higher in sensitised animals and was decreased in mice-fed RG or FRG. Furthermore, intestinal barrier-related markers such as MMCP-1, IL-4, TNF-α, COX-2 and iNOS mRNA expressions were decreased by RG or FRG.

Ginseng berry extract significantly inhibited the histamine releases in human leukemic mast cells at the concentration of 30 μg/mL and 10 μg/mL (Bae et al. 2012). The ginsenoside Re from ginseng berry at concentrations of 1, 3, 10 and 30 μM significantly reduced histamine secretion exhibiting 49.6 %, 47.2 %, 51.3 % and 79.0 %, respectively. In the cytokine assay experiments using human alveolar epithelial cells, the most effective inhibitory dosages of ginseng berry and ginsenoside Re were determined to be 30 μg/mL and 30 μM, respectively. Ginseng berry extract and Re reduced interleukin IL-1α, IL-8

and IL-10 and RANTES (regulated and normal T cell expressed and secreted) secretion induced by lipopolysaccharide treatment.

Cognitive Enhancing Activity

Ginseng had been reported to possess a plethora of physiological effects that could potentially benefit cognitive performance or mood (Kennedy and Scholey 2003). Animal studies showed that ginseng and its constituent ginsenosides could modulate indices of stress, fatigue and learning. Recent research had demonstrated that single doses of ginseng most notably engendered cognitive benefits in terms of improved memory but could also be associated with "costs" in terms of attention task deficits following less mnemonically beneficial doses. A single dose of ginseng had also been shown to modulate cerebroelectrical (EEG) activity. The authors suggested that ginseng would benefit from more rigorous research further delineating its acute effects and exploring the relationship between acute effects and those seen during and following chronic administration regimens.

Whereas single administration of Rf, Re and Rd significantly suppressed the conditioned avoidance response, repeated administration of them caused facilitation of the response (Kaku et al. 1975). In contrast, Rb_2 always showed very weak suppressant action. Rg_1, Rf, Re and Rd significantly suppressed the fighting of mice induced by footshock, while Rb_1, Rb_2 and Re little affected the fighting. Intraperitoneal administration of ginseng neutral saponins (GNS), a water-soluble fraction (GF4) free of saponins and a lipid-soluble fraction (GNo. 5) in Wistar male rats inhibited conditioned avoidance response (CAR) and discrimination ability between 500 Hz sound with electrical shock (SD) and 1,000 Hz sound without shock (Sdelta (Saito et al. 1977). Data from these tests indicated that *P. ginseng* root contained at least three sedative compounds. Acute intraperitoneal administration of crude ginseng saponin (CGS) (50 and 100 mg/kg) and pure ginsenoside Rb_1 (GS-Rb_1) (2.5 and 5 mg/kg) significantly suppressed maternal aggression in a dose-dependent manner, whereas ginsenoside Rg_1 (GS-Rg_1) was ineffective (Yoshimura et al. 1988a). The results indicated that ginseng root contained a psychoactive ingredient, GS-Rb_1, which could suppress maternal aggression. When the resident mouse was treated with crude ginseng saponins (25, 50 and 100 mg/kg i.p.), aggressive episodes (offensive sideways posture and attack bite) were significantly suppressed in a dose-dependent manner (Yoshimura et al. 1988b). However, the agonistic behaviour was not altered when the intruder mouse was treated with crude ginseng saponins. GS-Rb_1 (2.5, 5 and 10 mg/kg i.p.) also significantly suppressed aggressive episodes when given to the resident, whereas GS-Rg_1 (2.5, 5 and 10 mg/kg i.p.) was ineffective. Neither Gs-Rb_1 nor GS-Rg_1 given to the intruder caused any significant changes in the behaviour of the resident. Although the highest dose of crude ginseng saponins suppressed locomotion frequency, it appeared that both crude ginseng saponins and GS-Rb1 possessed a specific psychotropic action on agonistic behaviour.

Studies by Petkov and Mosharrof (1987) showed that ginseng at appropriate doses improved learning, memory and locomotive capabilities in mice. They found that administration of Gincosan (a combination preparation of ginseng and ginkgo) in rats elicited favourable effects on learning and memory using some conditioned reflex methods with punishment or positive reinforcement for active and passive avoidance (shuttle-box, step-down, step-through and water maze) (Petkov et al. 1993). Intraperitoneal administration of ginseng of protopanaxadiol (PD) and protopanaxatriol (PT) saponins improved the scopolamine-induced learning impairment at 50 and 100 mg/kg dosages in mice (Jin et al. 1999) but not in normal mice. Korean red ginseng saponin with a low PD/PT ratio improved spatial working memory, but the saponin with a high PD/PT ratio did not.

Lee et al. (2000a) suggested that repeated administration of red ginseng total saponins (RGTS) and *N*-methyl-D-glucamine (nootropic drug) ameliorated the impairing effect of ethanol on acquisition in passive avoidance performance, and the effect of RGTS on ethanol-induced

amnesia was dependent on the catecholaminergic but not serotonergic neuronal activity, while RGTS and *N*-methyl-D-glucamine appeared to have a different mechanism on ethanol-induced amnesia. Treatment with red ginseng significantly ameliorated place navigation deficits in young rats with hippocampal lesions on the place-learning task (PLT) in a circular open field (Zhong et al. 2000). Similarly, red ginseng improved performance of aged rats on the PLT task. The results suggested that red ginseng ameliorated learning and memory deficits through effects on the central nervous system, partly through effects on the hippocampal formation. The results of studies with three types of spatial-learning task [distance movement task (DMT), random-reward place search task (RRPST) and place-learning task (PLT)] in a circular open field suggested that pretreatment with the non-saponin fraction of red ginseng improved learning and memory in aged rats and that this amelioration by non-saponin might be attributed partly to augmentation of long-term potentiation in the hippocampal CA3 subfield in rats (Kurimoto et al. 2004). Qiao et al. (2005) found that an increase in contextual fear conditioning (CFC)-related neurogenesis may be one mechanism of ginseng's properties to enhance learning ability in rats. Neurogenesis in the hippocampus had been shown to be necessary for hippocampus-/amygdala-dependent learning tasks. Co-administration of ginseng and bromodeoxyuridine (BrdU) increased the percent freezing time and the number of BrdU-positive cells in the dentate gyrus of rats that received CFC.

A 30 % ethanol elution of ginseng roots was found to enhance memory in scopolamine-induced memory deficit rats after intraperitoneal administration (Wang et al. 2010b). Oligosaccharides and peptides were isolated from 30 % ethanol elution of ginseng roots. The oligosaccharides were identified as maltose, maltotriose, maltotetraose, maltopentaose, maltohexaose and maltoheptaose. Ginsenoside Rb_1, a potential phytoestrogen, had been shown to improve central nervous system dysfunctions, comparable to the oestrogen treatment (Hao et al. 2011). Administration of ginsenoside Rb1 and oestradiol to ovariectomised mice increased the neural 5-hydroxytryptamine (5-HT) concentration, elevated tryptophan hydroxylase and depressed monoamine oxidase activities in the frontal cortex and striatum. Ginsenoside Rb_1 and oestradiol also improved object recognition and decreased immobility time in the forced swimming test. Treatment of mice with ginseng ginsenosides Rg_5 or Rh_3 increased the latency time reduced by scopolamine in passive avoidance test and significantly reversed the lowered spontaneous alteration induced by scopolamine in Y-maze task (Kim et al. 2013b). Ginsenoside Rg_5 or Rh_3 (10 mg/kg) significantly shortened the escape latencies prolonged by treatment with scopolamine on the last day of training trial sessions in Morris water maze task. The protective effects of both ginsenosides on memory impairment induced by scopolamine were mediated by inhibiting acetylcholinesterase activity and increasing hippocampal brain-derived neurotrophic factor expression and cAMP response element-binding protein activation.

A novel tetradecapeptide purified from ginseng polypeptides exhibited memory enhancing activity in mice using Morris water maze task (Luo et al. 2013). Chu et al. (2014) demonstrated that ginseng ginsenoside Rg_5 improved cognitive dysfunction and attenuated neuroinflammatory responses in streptozotocin (STZ)-induced memory impaired rats. Cognitive deficits were ameliorated with Rg_5 (5, 10 and 20 mg/kg) treatment in a dose-dependent manner together with decreased levels of inflammatory cytokines TNF-α and IL-1β in brains of STZ rats. Acetylcholinesterase activity was also significantly reduced by Rg_5, whereas choline acetyltransferase activity was markedly increased in the cortex and hippocampus of STZ-induced Alzheimer's disease rats. Rg_5 enhanced the expressions of insulin-like growth factors 1 (IGF-1) and brain-derived neurotrophic factor (BDNF) but decreased significantly Aβ deposits in the hippocampus and cerebral cortex. The expressions of COX-2 and iNOS which were significantly upregulated in STZ-induced Alzheimer's disease rats were downregulated strongly by Rg_5 compared with control rats.

Clinical Studies

In a double-blind, placebo-controlled clinical study of 16 healthy male volunteers, administra-

tion of Korean ginseng (G 115; 100 mg twice a day for 12 weeks) was found to be superior to placebo in improving certain psychomotor functions in healthy subjects (D'Angelo et al. 1986). Korean ginseng G 115 elicited a favourable effect relative to baseline performance in attention (cancellation test), processing (mental arithmetic, logical deduction), integrated sensory motor function (choice reaction time) and auditory reaction time. In a 12-week placebo-controlled, double-blind, randomised study involving 185 subjects taking placebo and 205 subjects taking a combination of vital substances, including ginseng extract G115, the latter had significant, favourable advantages over placebo therapy (Wiklund et al. 1994). According to the visual analogue scales scores, subjects receiving the combination of active substances improved significantly more in alertness, relaxation, appetite and overall score. Among a subgroup of subjects with the 20 % lowest scores at baseline, the combination treatment improved both vitality and depressed mood.

In a placebo-controlled, double-blind, balanced crossover study of 20 healthy young adult volunteers, acute administration of *P. ginseng* modulated mood and cognitive performance (Kennedy et al. 2001). There was a significant improvement in "Quality of Memory" and associated "Secondary Memory" factor at all times following 400 mg ginseng. Both 200 and 600 mg doses were associated with a significant decrease of the "Speed of Attention" factor at later testing times only. In another 20-week double-blind placebo-controlled crossover study of 25 volunteers, chronic ingestion of ginseng G115 elicited improvements in working memory and decrements in aspects of cognition and mood (Reay et al. 2008). In a double-masked, randomised, test–retest design of 112 healthy subjects (>40 years old), the group administered with ginseng (55) showed a tendency to faster simple reactions and significantly better abstract thinking than the placebo group (57) (Sørensen and Sonne 1996). However, there was no significant difference between the two groups in concentration, memory or subjective experience.

Hypolipidemic Activity

Administration of ginseng ginsenoside Rb_1 to rats during early feeding was found to reverse adverse effects of high-fat diet characterised by a higher level of cholesterol in liver and a lower incorporation of ^{14}C-acetate into liver cholesterol and a repressed activity of HMG-CoA reductase, a key enzyme in cholesterol biosynthesis (Ikehara et al. 1978). Streptozotocin-induced diabetic rats treated with ginsenoside Rb2 showed significant decreases in triglyceride, nonesterified fatty acid and total cholesterol in the serum (Yokozawa et al. 1985b, 1987b). A lipid-improving action in the serum was observed in rats with hyperlipidemia. Further, the lipolytic activity of lipoprotein lipase was stimulated with a concomitant decrease in the levels of triglyceride and very low-density lipoprotein in the serum, while a repressive effect on hormone-sensitive lipase activity was observed. The accumulation of lipid in the adipose tissue was also observed. The rats treated with ginsenoside Rb2 showed a significant decrease of glucose in the hepatic tissue. The level of hepatic glycogen was slightly increased after ginsenoside Rb2 administration. The glucose-6-phosphate level tended to increase, the pyruvate level was unchanged and the lactate level tended to decrease. There was, however, no accumulation of total lipid in hepatic tissue. Besides the hypolipidemic effect, ginsenoside Rb2 lowered serum levels of 3-hydroxybutyrate and acetoacetate in streptozotocin-induced diabetic rats, indicating an improvement of diabetic ketoacidosis. A single intraperitoneal administration of ginsenoside Rb_2 produced a significant decrease of total cholesterol, free cholesterol, low-density lipoprotein (LDL) cholesterol, triglyceride, 3-hydroxybutyrate and acetoacetate levels in the serum in rats fed on a high-cholesterol diet (Yokozawa et al. 1985a). However, a significant increase of high-density lipoprotein (HDL) cholesterol level in the serum was observed after the treatment. Repeated administration of ginsenoside Rb2 to rats with hyperlipidemia induced by a high-cholesterol diet resulted in a striking decrease in the levels of total cholesterol, free cholesterol, LDL cholesterol and triglyceride,

whereas the level of HDL cholesterol was again increased. Further, the lipolytic activity of lipoprotein lipase was stimulated with a concomitant decrease in the levels of triglyceride and very low-density lipoprotein (VLDL)-triglyceride in the serum. Accumulation of lipid in the adipose tissue was observed.

Cholesteryl ester transfer protein (CETP) inhibitors identified as polyacetylene analogues were isolated from Korean ginseng root extract (Kwon et al. 1996). These compounds inhibited human CETP with IC_{50} values of around 20–35 mg/ml. Acyl-CoA cholesterol acyltransferase (ACAT) inhibitors were isolated from ginseng hairy roots and identified as panaxynol, panaxydol, panaxydiol and panaxytriol (Kwon et al. 1997). These active compounds inhibit rat liver ACAT with IC_{50} values of 94, 80, 45 and 79 μM, respectively. Ginseng saponins very mildly inhibited Acyl-CoA cholesterol acyltransferase (ACAT) in-vitro; however, ginseng sapogenins produced from ginseng saponins showed strong inhibitory activity on microsomal ACAT, indicating them to be key ingredients of ginseng in lowering of the serum total cholesterol level (Kwon et al. 1999). Oral administration of ginseng saponins at a dose of 0.01 g/kg for 4 weeks was found to reverse the increase in serum triglycerides (TG) and concomitant increase in cholesterol produced by cyclophosphamide treatment in fasted rabbits, especially in chylomicrons and very low-density lipoprotein (VLDL) (Inoue et al. 1999). In addition, ginseng saponins treatment led to a recovery in postheparin plasma lipoprotein lipase activity and heparin-releasable heart lipoprotein lipase activity, which were markedly reduced by cyclophosphamide treatment. In rats given 15 % glycerol/15 % fructose solution, postheparin plasma lipoprotein lipase activity declined to two thirds of normal rats, whereas ginseng saponins reversed it to normal levels. Phenolic compound-rich extracts from white ginseng were found to be effective in part in improving hyperlipidemia and atherosclerosis induced by a high-cholesterol diet among New Zealand white rabbits (Lee et al. 2013d). Antioxidant enzyme activities and morphological changes of the aorta showed that white ginseng small compounds had a positive effect on hypercholesterolemia.

Serum total cholesterol, triglyceride, low-density lipoprotein and plasma malondialdehyde levels were decreased by administration of *Panax ginseng* extract for 8 weeks (6 g per day) in humans; however, high-density lipoprotein, catalase and superoxidase activities were increased (Kim and Park 2003). The results supported scientific claims that ginseng had hypolipidemic potential and that the antioxidant potential of ginseng extract might induce hypolipidemic effect as one of the mechanism. Two polyacetylenic compounds, (9*R*,*10*S)-epoxyheptadecan-4,6-diyn-3-one and 1-methoxy-(9*R*,10*S*)-epoxyheptadecan-4,6-diyn-3-one (Lee et al. 2004b) and (9*R*,10*S*)-epoxy-16-heptadecene-4, 6-diyne-3-one (Rho et al. 2005), obtained from the petroleum ether extract of ginseng, showed significant Acyl-CoA cholesterol acyltransferase (ACAT) inhibition.

Antihyperglycaemic/Antidiabetic Activity

In-Vitro Studies

A hypoglycaemic principle, panaxan B, was obtained from ginseng roots (Tomoda et al. 1985). The aqueous ethanolic extract of Korean red ginseng significantly evoked a stimulation of insulin release from isolated rat pancreatic islets in a glucose-independent manner (Kim and Kim 2008). The results suggested that red ginseng may have beneficial effects in the treatment of diabetes. Ginsenoside Rg_2 significantly inhibited hepatic glucose production and induced phosphorylations of liver kinase B1 (LKB1), AMP-activated protein kinase (AMPK) and glycogen synthase kinase 3β (GSK3β) in time- and concentration-dependent manners in human HepG2 hepatoma cells (Yuan et al. 2012). Rg_2 markedly enhanced the gene expression of small heterodimer partner (SHP).

Studies by Gao et al. (2013b) found that ginsenoside Re exhibited the action of reducing insulin resistance through activation of PPAR-γ (peroxisome proliferator-activated receptor gamma) pathway by directly increasing the expressions of PPAR-γ2 and its responsive genes – adiponectin, IRS-1 (insulin receptor

substrate-1) and ap2 (fatty acid binding protein). Re also inhibited TNF-α (tumour nuclear factor-alpha) production and facilitated the translocation of GLUT4 (glucose transporter type 4) in promoting glucose uptake and disposal in 3T3-L1 adipocytes. Compound K (CK), a final intestinal metabolite of protopanaxadiol-type ginsenosides from *Panax ginseng*, exhibited anti-diabetic activity; it significantly enhanced insulin secretion, increased cellular ATP content and upregulated the expression of GLUT2 in MIN6 pancreatic β-cell lines in-vitro (Gu et al. 2013).

Animal Studies

The hyperglycaemia induced by adrenaline or alloxan could be restrained by ginseng in rabbits (Yamada 1955). Streptozotocin-induced diabetic rats treated with ginsenoside Rb_2 showed a significant decrease of blood glucose level (Yokozawa et al. 1985c). A moderate (but statistically insignificant) increase in the hepatic glycogen content was observed. Further, the ginsenoside Rb_2-treated group showed a significant rise of glucokinase activity in the liver, while there was a significant decrease in the activity of glucose-6-phosphatase. The results suggested that the changes of glucokinase and glucose-6-phosphatase levels may be one of the mechanisms of the hypoglycaemic action produced by ginsenoside Rb_2.

Five types of hypoglycaemic and insulinomimetic substances had been discovered on ginseng (Ng and Yeung 1985). These included five glycans designated panaxans A–E, adenosine, a carboxylic acid, a peptide with a molecular weight of 1,400 and lacking in basic amino acid residues and a fraction designated DPG-3-2 prepared from the water extract of ginseng. The glycans had been demonstrated to elicit hypoglycaemia in both normal and diabetic mice. DPG-3-2 exerted its hypoglycaemic action or provoked insulin secretion in diabetic and glucose-loaded normal mice while having no effect on normal mice. Adenosine inhibited catecholamine-induced lipolysis in rat epididymal fat pads. Four glycans, panaxans I, J, K and L from ginseng roots, markedly reduced blood sugar levels in normal and alloxan-induced hyperglycaemic mice (Oshima et al. 1985). Panaxans Q, R, S, T and U isolated from ginseng roots displayed marked hypoglycaemic action in normal and alloxan-induced hyperglycaemic mice (Konno et al. 1985).

C57BL/Ks *db*/*db* mice treated with daily intraperitoneal injections of ginseng berry extract at 150 mg/kg body weight for 12 consecutive days had lower fasting glucose levels and improved glucose tolerance compared with vehicle-treated mice (Xie et al. 2002). Adult mice and littermates treated with ginseng berry showed marked weight loss. In a another study, Dey et al. (2003) found that ginseng berry exhibited more potent antihyperglycaemic activity than ginseng root and only ginseng berry also showed marked antiobesity effects in *ob*/*ob* mice. After 12 days of treatment with ginseng berry extract, overall glucose exposure improved significantly, and the AUC decreased by 31.0 %. Additionally, body weight did not change significantly after ginseng root extract (150 mg/kg body wt.) treatment, but the same concentration of ginseng berry extract significantly decreased body weight.

Wild ginseng leaf extract supplementation suppressed a sudden increase in blood glucose levels and a consequent decrease in TBARS levels in streptozotocin (STZ)-induced diabetic rats (Jung et al. 2005a). TBARS levels in the liver, kidney and spleen of ginseng extract-fed diabetic groups were also significantly lower than in the control diabetic group indicating that oral administration of ginseng extract effectively suppressed lipid peroxidation that occurred in the organs of diabetic rats. Additionally, ginseng extract supplementation further suppressed activities of antioxidant-related enzymes, such as glutathione peroxidase (GSH-Px), catalase (CAT) and superoxide dismutase (SOD), in organs of diabetic rats. The results confirmed the effectiveness of WGLE ginseng leaf extract supplementation in detoxifying free radicals that were produced excessively in diabetic-induced complications. Intraperitoneal injections of diabetic C57BL/6J *ob*/*ob* mice with total ginsenosides in Chinese ginseng significantly lowered the fasting blood glucose levels and body weight and markedly improved glucose tolerance (Xie et al. 2005).

Studies demonstrated that ginseng ginsenoside Re could lower blood glucose and lipid levels and exerts protective actions against the occurrence of oxidative stress in the eye and kidney of streptozotocin-induced diabetic rats (Cho et al. 2006). The data also provided evidence that ginsenoside Re could be used as an effective antidiabetic agent particularly in the prevention of diabetic microvasculopathy. Oral administration of *Panax ginseng* root (125.0 mg/kg) into rats three times daily for 3 days after receiving fructose-rich chow for 4 weeks reversed the increased glucose–insulin index, indicating that ginseng root had the ability to improve insulin sensitivity and delay the development of insulin resistance (Liu et al. 2005). Further they found that single intravenous injection of ginsenoside Rh2, from ginseng root, decreased the plasma glucose concentrations in 60 minutes in a dose-dependent manner from 0.1 to 1 mg/kg in rats with insulin resistance induced by fructose-rich chow (Lee et al. 2007c). Repeated intravenous injection of ginsenoside Rh2 (1 mg/kg per injection, three times daily) into rats which received fructose-rich chow for three consecutive days decreased the value of glucose–insulin index, the product of the areas under the curve of glucose and insulin during the intraperitoneal (i.p.) glucose tolerance test. Further, repeated injection of ginsenoside Rh_2 at the same dosing (1 mg/kg, three times daily) into streptozotocin-diabetic rats for 10 days elicited an increase of the responses to exogenous insulin. Lee et al. (2006c) found from their studies that ginsenoside Rh2 may be applied as an adjuvant for the management of diabetes as it possessed plasma glucose-lowering action and had the ability to increase insulin secretion as a result of the release of acetylcholine from nerve terminals that then stimulated muscarinic M(3) receptors in pancreatic cells. The results of studies by Su et al. (2007) suggested that *P. ginseng* root had the ability to increase the release of acetylcholine from nerve terminals in Wistar rats so as to stimulate muscarinic M_3 receptors activity located in the pancreatic cells for the enhanced secretion of insulin, which in turn lowered plasma glucose. Ninety minutes after the oral administration of *P. ginseng* root to fasting Wistar rats, plasma glucose decreased in a dose-dependent manner. Ginseng modified the diabetic phenotype and genes associated with diabetes in the male Zucker diabetic fatty rat (Banz et al. 2007). Animals treated with ginseng exhibited increased body weight and decreased kidney weight and cholesterol levels compared to control animals. Furthermore, ginseng exerted marked effects on the expression of genes involved in PPAR actions and triglyceride metabolism compared to controls.

Intravenous injection of malonyl-ginsenosides (MGR) (120 mg/kg), extracted from ginseng roots, to streptozotocin-induced diabetic mice reduced fasting blood glucose level (Liu et al. 2009). The same dose also exerted a marked improvement in glucose tolerance of 80 % in diabetic mice after 4 days. Korean red ginseng (KRG) extract significantly lowered blood glucose levels and improved glucose challenge testing when applied as prophylaxis in streptozotocin-induced type 1 diabetes (T1D) mice (Hong et al. 2012). Immune compartments of diabetic mice were found to be preserved in KRG-treated mice suggesting that Korean red ginseng may benefit T1D patients, not only for its hypoglycaemic but also for its immunomodulatory effects. Administration of taurine or ginseng or their mixture elicited marked amelioration in glucose, glycosylated haemoglobin (HbA1C), insulin and free T_3 levels in streptozotocin-diabetic rats (Saleh 2012). Combination treatment induced a significant reduction in serum cholesterol, triglycerides and low-density lipoprotein levels and a significant decrease in the activities of cardiac enzymes, aspartate aminotransferase (AST), creatine kinase (CK), lactate dehydrogenase (LDH) and the levels of serum endothelin-1 with a significant elevation in the levels of serum total nitric oxide (TNO) in diabetic rats. Treatment of high-fat/streptozotocin-induced diabetic mice with ginseng protopanaxadiol-type ginsenoside and its metabolite compound K exerted a hypoglycaemic effect as demonstrated by lowering of fasting blood glucose, and insulin-sensitising effects were seen during oral glucose tolerance testing (Li et al. 2012f). Gluconeogenic genes, phospho-

enolpyruvate carboxykinase (PEPCK) and glucose-6-phosphatase (G6Pase) were decreased in the two treatment groups with compound K showing greater effects. Administration of ginseng malonyl ginsenosides alleviated hyperglycaemia, hyperlipidemia and insulin resistance of high-fat diet-fed and streptozotocin-induced diabetic rats (Liu et al. 2013). Twelve-week supplementation with Korean red ginseng aqueous extract significantly decreased blood glucose of spontaneously diabetic Goto-Kakizaki rats compared to control (Kim and Kim 2012). The results suggested that glucose transporter (GLUT) 4 in adipose tissue, protein tyrosine phosphatases (PTP)-1B in adipose tissue and skeletal muscle, insulin, uncoupling protein (UCP) 2, Bax and poly (ADP-ribose) polymerase (PARP) in pancreas may be the primary targets of red ginseng that resulted in increase in insulin action and in insulin secretion and decrease in β-cell mass, and that normalised glucose homeostasis. Korean red ginseng (KRG) supplementation to high-fat diet-fed rats improved whole body insulin resistance and plasma lipid profiles (Jung and Kang 2013). Plasma free fatty acid concentrations and resting plasma insulin and glucose levels were significantly decreased after KRG supplementation. Liver and muscle triglyceride concentrations were also decreased in the KRG treatment group. Studies found that compound K, a final metabolite of ginseng panaxadiol ginsenosides, could improve body weight and food intake of high-fat diet/streptozotocin-induced diabetic rats (Jiang et al. 2014). CK exhibited dose-dependent reduction of fasting blood glucose, total glycerides and total cholesterol of diabetic rats; enhanced fasting serum insulin and insulin sensitivity; and improved glucose tolerance. The expression of InsR (insulin receptor), IRS1 (insulin receptor substrate-1), PI3Kp85 (phosphatidyl inositol 3-kinase p85), pAkt (serine/threonine kinase Akt phosphorylation) and Glut4 were enhanced in skeletal muscle tissue of diabetic rats. The results indicated that the hypoglycaemic activity of CK was mediated by improvement of insulin sensitivity, which was closely related to PI3K/Akt signalling pathway.

Clinical Studies

In a randomised, double-blind, placebo-controlled study of 19 participants with well-controlled type 2 diabetes, 12 weeks of supplementation with a Korean red ginseng preparation gave good glycaemic control and improved plasma glucose and plasma insulin regulation safely beyond usual therapy (Vuksan et al. 2008). Korean ginseng rootlets had >sixfold total ginsenosides more than the Korean ginseng root but did not significantly affect postprandial glucose in healthy individuals (De Souza et al. 2011). Despite a reduced ginsenoside profile, Korean ginseng root lowered postprandial glucose levels at 45, 60, 90 and 120 minutes during the test, rendering an overall reduction of 27 % in incremental area under the glucose curve compared to the control.

Immunomodulatory Activity

The phagocytosis index increases by oral application of ginseng in rabbits, and an increase of γ-globulin in blood serum was proven (Yamada 1955). Ginseng total saponin interacted with multilamellar liposomes (composed of egg phosphatidylcholine, phosphatidic acid and/or cholesterol) and prevented them from behaving as an ideal osmometer (Yu et al. 1985). 20-*S*-Protopanaxadiol saponin showed similar activity but 20-*S*-protopanaxatriol saponin had weak activity. Ginsenoside Rb_1 disturbed osmotic behaviour of cholesterol-free liposomes, but not cholesterol-containing liposomes as monomers, and lysed both liposomes as micelles. Rg_1, whose genin was 20-*S*-protopanaxatriol, showed no activity on liposomes with or without cholesterol. The study suggested that ginseng saponins may interact with and destroy liposomal membranes and that structure of sugar moiety was an important factor to their activities. Porcine parvovirus (PPV) vaccines containing ginseng fraction Rb_1 induced serum-detectable amounts of IL-4 and IL-10 as early as 24 hours after primary injection in mice (Rivera et al. 2005). Five weeks after booster, immune lymphocytes were still producing large

amounts of cytokines including IFN-γ, IL-2, IL-4, IL-10 and TNF-α, and the antibody titres were still similar to those titres recorded 1-week post-booster. The Rb1 adjuvanted vaccines stimulated similar titres of antigen-specific IgG1, IgG_{2a} and IgG_{2b}. Thus, the cytokine and the serological data indicated that the Rb_1 fraction of ginseng elicited a balanced Th1 and Th2 immune response.

Su et al. (2010) found that total saponins of *Panax ginseng* could inhibit the immune maturation of dendritic cells induced by oxidised low-density lipoprotein partly via the PPAR-γ pathway and may have beneficial effects on atherosclerosis. Ginsenoside Rg_6 and ginsenoside F_4 from steamed ginseng flowers and leaves exhibited particularly inhibitory effect on LPS-induced interleukin IL-12 production with the inhibition values of 80 and 82 %, and ginsenoside ST_1, ginsenoside SL_2, ginsenoside SL_3, ginsenoside Rh_3, ginsenoside Rk_2 and ginsenoside Rs_4 showed moderate effects with inhibition rates of 63, 65, 67, 68, 71, 73 and 67 %, respectively (Tung et al. 2011).

Seventy percent methanol red ginseng extract was found to promote phagocytic activity of the reticuloendotherial system in normal mice and carrageenan- or cyclophosphamide-treated mice (Matsuda et al. 1985). The acidic fraction of ginseng polysaccharide was more effective in increasing the ratio of spleen to body weight, the number of antibody secreting cells to sheep red blood cells (SRBC) and phagocytic activity of reticuloendothelial system, as well as antitumour activity against the solid form of sarcoma 180 in ICR mice than the neutral fraction (Kim et al. 1990). All polysaccharide fractions were mitogenic to cultured spleen cells of C57BL/6 mice. Both crude and acidic fractions potentiated remarkably the mitogenic activity of phytohaemagglutinin-P (PHA-P) or lipopolysaccharide (LPS) in dose-dependent manner, but the neutral fraction enhanced only that of LPS. All three polysaccharide fractions had no effect on that of concanavalin A. The results suggested that the acidic fraction may stimulate B and T cells as well as macrophages, while the neutral fraction may stimulate only B cells and macrophages. Administration of GL-4IIb2, acidic ginseng leaf polysaccharide containing 33 % uronic acid, to mice significantly and dose dependently enhanced immune complexes clearance from circulation compared to control (Sun et al. 1994). It was found that the carbohydrate moiety of GL-4IIb2 activated the mononuclear phagocytic system in-vivo through an increase of Fc receptor (FcR) expression mediated by de novo synthesis of the receptor protein and resulted in enhanced immune complexes clearance.

The extracts of hot water-soluble fraction from wild *Panax ginseng* but not from cultured *Panax ginseng* showed mitogenic activity to lymphocytes (Mizuno et al. 1994). The mitogenic activity of wild *Panax ginseng* (100 μg/well) was almost equal to concanavalin A (0.1 μg/well) which was well known as one of the T cell mitogens. The percentages of Thy1.2-(pan T cells), L3T4-(helper T cells) and Lyt2-(cytotoxic T cells) positive cell population were significantly increased in mice orally administered hot water-soluble fraction from wild *Panax ginseng* as compared to control by 31.2, 17.9 and 30.1 %, respectively. The pectic polysaccharide (GL-4IIb2) isolated from ginseng leaves was found to be a macrophage Fc receptor expression enhancing polysaccharide (Shin et al. 1997). Other polysaccharides from the leaves, GL-4IIb2 and GL-RIII, had relatively potent interleukin 6 (IL-6) production enhancing activity of macrophages; however, GL-RI and GL-RII had negligible and weak enhancing activities, respectively (Shin et al. 1998).

Cell cultured ginseng polysaccharides (CCGPS) increased the weight of spleen and enhanced the clearance rate of intravenous charcoal particles in mice and significantly promoted the production of activity of haemolysins antibody and also raised the level of IgG in mice serum (Ding et al. 1993). They also enhanced delayed-type hypersensitivity of footpad induced by SRBC in mice indicating that CCGPS also strengthened body resistance and restored normal functioning of the body. Intraperitoneal administration of ginseng acidic polysaccharide generated a high-output nitric oxide synthase (iNOS)

in female BALB/c mice (Park et al. 2001). This study showed that the immunomodulating activities of the acidic polysaccharide were mediated by the production of nitric oxide. A study suggested that ginseng acidic polysaccharide played marked immunostimulating role on the maturation of murine B bone marrow dendritic cells through precise modulation of phagocytosis and acid phosphatase activities inside the dendritic cells (Wang et al. 2013c).

In-vitro and in-vivo studies showed that the acidic polysaccharide ginsan could potentially be an ideal nontoxic antineoplastic immunostimulator by activating multiple effector arms of the immune system (Lee et al. 1997). Ginsan induced the proliferation of T cells and B cells, generated ginsan-activated killer (AK) cells and stimulated macrophages to produce reactive nitrogen intermediates and become tumouricidal. Ginsan exhibited significant in-vivo antitumour activity against B16 melanoma cells lines and in the benzo(a)pyrene-induced autochthonous lung tumour model, at much lower doses than the maximum tolerated doses. Studies also demonstrated that ginsan generated lymphokine-activated killer (LAK) cells from both NK and T cells through endogenously produced multiple cytokines (Kim et al. 1998b). This property may contribute to its effectiveness in the immunoprevention and immunotherapy of cancer. Ginsan synergised with rIL-2 to generate LAK cells (2.0–15-fold) and the most dramatic synergy was seen at rIL-2 concentrations below 3 U/ml. Ginsan alone inhibited pulmonary metastasis of B16-F10 melanoma cells and enhanced the inhibition of lung colonies by rIL-2. Another acidic polysaccharide from ginseng root, ginsenan S-IIA, was found to be a potent inducer of interleukin IL-8 production by human monocytes and THP-1 cells, and this induction was accompanied by increased IL-8 mRNA expression (Sonoda et al. 1998). Administration of ginseng total saponin ameliorated morphine-induced immune suppression by blocking morphine-induced apoptosis of thymocytes and elevation of serum corticosterone (Kim et al. 1999f). Atrophy of thymus and spleen and decrease in body weight increment rate caused by morphine were partly reversed by concomitant administration of ginseng total saponin.

In-vitro studies showed that ginsan exerted effective immunomodulatory activity and enhanced antitumour activity of macrophages (Song et al. 2002). Murine peritoneal macrophages on in-vitro treatment with ginsan induced mRNA of cytokines such as tumour necrosis factor (TNF)-α, interleukin 1 (IL-1)beta, interleukin 6 (IL-6) and interleukin 12 (IL-12). Ginsan enhanced the lytic death of L929 cells through TNF-α activation. The mRNA expression of nitric oxide synthase (iNOS) was highly induced after 24 hour treatment of ginsan, and then NO production was maximum after 48 hour treatment with a low dose of 1 μg/ml. The tumouricidal activity of macrophage cultured with ginsan on Yac-1 cells was enhanced in a dose-dependent manner; growth inhibition increased 1.6-fold with 100 μg/ml ginsan. Ginsan restored the T lymphocytes function that had been suppressed by gamma irradiation in allogeneic MLR (mixed lymphocyte reactions) (Han et al. 2005). Ginsan was found to stimulate murine normal splenocytes by inducing the mRNA expressions of Th1 and Th2 type cytokines and also restored the mRNA expression of IFN-gamma, Th1 cytokine, after its inhibition by whole-body gamma irradiation. Ginsan exhibited immunomodulatory effects on dendritic cells (DCs) (Kim et al. 2009a). Ginsan markedly increased the levels of production by DCs of IL-12 and TNF-α and enhanced the expression of CD86 on DC surfaces. In ^{3}H-thymidine incorporation assays, ginsan-treated DCs stimulated significantly higher proliferation of allogeneic $CD4^{+}$ T lymphocytes than did medium-treated DCs. The study demonstrated that ginsan stimulated dendritic cells by inducing maturation. Ginsan significantly enhanced viability and proliferation of spleen cells (Ko and Joo 2010). Multiple clusters, indicating proliferation, were observed in ginsan-treated spleen cells, and carboxyfluorescein succinimidyl ester and surface marker staining assay revealed that ginsan promoted proliferation from CD19(+) B cells rather than CD4(+) or CD8(+) T cells. In addition, ginsan decreased the percentage of late apoptotic cells. Ginsan increased the

surface expression of CD25 and CD69 as well as production of interleukin 2 from spleen cells, suggesting increased activation. Taken together, these results demonstrate that ginsan increases the viability and proliferation of spleen cells via multiple mechanisms. Ginsan effectively enhanced the humoral immune response to orally delivered *Salmonella* antigen, mediated by CCL3 mRNA expression via COX (Na et al. 2010). The results suggested that ginsan may serve as a potent vaccine supplement for oral immunisation.

Ginseng acidic polysaccharide, ginsan, significantly ameliorated the progression of experimental autoimmune encephalomyelitis (an animal model of human multiple sclerosis) by inhibiting the proliferation of autoreactive T cells and the production of inflammatory cytokines such as IFN-γ, IL-1β and IL-17 (Hwang et al. 2011). More importantly, ginsan promoted the generation of immunosuppressive regulatory T cells (Tregs) through the activation of transcription factor, Foxp3. The results suggested that ginsan may serve as an effective therapy for multiple sclerosis and other autoimmune diseases. Treatment of water-extracted oligosaccharide from ginseng roots significantly increased phagocytosis of macrophages and promoted NO, tumour necrosis factor-α (TNF-α) and reactive oxygen species production (Jiao et al. 2012). Further, ginseng oligosaccharide extract dose dependently stimulated NO formation through the upregulation of inducible NO synthase (iNOS) activity. Ginseng oligosaccharide extract was found to possess high immunopotentiating activity and could be developed as a novel immnunostimulant. Treatment of hepatoma-22 (H22)-bearing mice with water-soluble ginseng oligosaccharides (WGOS) inhibited tumour growth and significantly increased relative spleen and thymus weight, serum tumour necrosis factor-α level, spleen lymphocyte proliferation, natural killer cell activity, phagocytic function and nitric oxide production secreted by macrophage (Jiao et al. 2014b). However, no direct cytotoxicity was detected; thus, the authors concluded that the antitumour activity of WGOS may be related to their immunomodulatory effects. The study by Liu and Zhang (1996) suggested that one of the mechanisms by which ginsenoside Rg_1 enhanced immune function in old rats might be mediated by the increase of intracellular cAMP and cGMP contents, resulting in interleukin IL-2 gene expression and splenocyte proliferation. Kim et al. (1997) found that long-term oral administration of ginseng extract decreases serum γ-globulin and immunoglobulin IgG_1 isotypes in mice. Among the immunoglobulin Ig isotypes, including IgG_1, IgG_{2a}, IgG_{2b}, IgG_3, IgM and IgA, serum IgG_1 was dose dependently decreased to 68 % of control values at the dose of 150 mg/kg per day without significant changes in other Ig isotypes. However, the α_1-globulin level increased by 24 % at the doses of 30 and 150 mg/kg per day.

Lymphocyte proliferation assays showed that both the neutral polysaccharides and acidic polysaccharides of ginseng roots were potent B and T cell stimulators (Zhang et al. 2009). Water-soluble ginseng oligosaccharides (designated as WGOS) were found to be potent B and T cell stimulators, and its fraction WGOS-1 exerted the highest immunostimulating effect on lymphocyte proliferation among those purified fractions, indicating WGOS potential to be developed into functional food or medicine (Wan et al. 2012). Studies showed that ginseng ginsenosides Rg1 and Re had adjuvant activities in stimulating IgG, splenocyte proliferation and mRNA expression of cytokines IL-4, IL-10, IL-12 and IFN-γ as well as transcription factors GATA-3 and T-bet by splenocytes in C3H/HeB mice but not in C3H/HeJ mice carrying a defective toll-like receptor-4 (TLR4) gene (Su et al. 2012). The results suggested that TLR4 signalling pathway was involved in the adjuvant activities of Rg_1 and Re. Nevertheless, pretreatment with anti-TLR4 antibody suppressed the Re- but not Rg1-induced expression of NF-κB, indicating that Rg1 may trigger both extracellular and intracellular TLR4 by passing through the cell membrane, while Re only activates extracellular TLR4 as it failed to enter inside of the cells to stimulate intracellular TLR4.

Sun et al. (2007) indicated that ovalbumin-specific antibody responses were significantly

higher in mice immunised with ovalbumin co-administered with Rg_1, Re, Rg_2, Rg_3 and Rb_1 but not with Rd, Rc and Rb_2 when compared with the control (immunised with ovalbumin only). Significantly enhanced splenocyte proliferative responses to Con A, LPS and ovalbumin as well as the production of both IL-5 and IFN-γ stimulated by ovalbumin were also detected in mice immunised with ovalbumin co-administered with Rg1 but not with Rb1, Re and Rg3. Of the ginsenosides studied, Rg1, Re, Rg2, Rg3 and Rb1 exhibited more potent adjuvant properties than the others, indicating that they are the major constituents contributing to the adjuvant activities of total ginseng saponins.

Three dammarane triterpenes from ginseng leaves significantly increased interleukin 12 expression in LPS-activated mouse peritoneal macrophage (Tran et al. 2014). Further, the new compound, 27-demethyl-(*E*,*E*)-20(22),23-dien-3β,6α,12β-trihydroxydammar-25-one, strongly increased the Th1 response-mediated cytokine IL-2 and decreased Th2 response-mediated cytokines IL-4 and IL-6 expression. Su et al. (2014) found that supplementation of ginseng ginsenoside (5.00 mg/kg) to 20 μl of inactivated rabies virus vaccine (RV) significantly amplified serum antibody responses and increased the $CD4^+$:$CD8^+$ ratio, interleukin IL-4, IL-10, IL-12 and IFN-γ secretions and Th1/Th2 responses inducing similar protection as did 100 μl of RV in ICR mice. This suggested that ginseng ginsenoside Re could be used to reduce the dose and therefore the cost of the RV to achieve the same effective protection.

In a study of four normal healthy adult volunteers, increasing concentration of *P. ginseng* (0.16–1.6 μg/ml) caused a dose-related inhibition of phytohaemagglutinin (PHA-P)-induced transformation of peripheral blood lymphocytes (Chong et al. 1982). A combination of 500 μg/ml hydrocortisone and 0.80 μg/ml *P. ginseng* produced a greater suppression of PHA-P stimulation than either drug used alone. This suggested that *Panax ginseng* had a steroidlike effect in-vitro and may have a potentiating effect with hydrocortisone on T cell-mediated immunity. In a study of 10 young and 19 elderly persons, phytohaemagglutinin and Rg1 had stimulative effects on the phenotype of lymphocytes (Liu et al. 1995). Rg1 also increased the fluidity of lymphocyte membrane of the aged. The CD_{25} and CD_{45}RA positive cells of lymphocytes in the elderly were lower than those of the young people. More CD_{45}RO-positive cells than CD_{45}RA-positive cell lymphocyte populations were seen in the aged.

Anticomplementary Activity

Four anticomplementary polysaccharides, GL-PI to GL-PIV, and GL-PII, were isolated from ginseng leaves (Gao et al. 1988, 1990). Twelve ginsenosides were isolated from ginseng and exhibited definite anticomplement activity on complements C1q, C2, C3, C4 and C5, however, not C9 (Gao et al. 2013a). Sugar moiety was found to facilitate the anticomplement activity for oleanolic acid type ginsenosides. The targets researched partly explained the anti-inflammatory activity of some ginsenosides. *Panax ginseng* extract G-115 had anticomplementary and mitogenic activities (Yamada et al. 1995). Incubation with artificial gastric juice slightly decreased the anticomplementary activity, whereas incubation with artificial intestinal juice or with artificial gastric juice followed by artificial intestinal juice slightly increased the activity. The most potent anticomplementary activity was observed in the crude polysaccharide fraction, G-115G, whereas the water-soluble dialysable fraction, G-115E, showed the most potent mitogenic activity.

Cardiovascular/Cardioprotective Activities

In-Vitro Studies

Ginsenosides and chikusetsusaponins present in the roots of *Panax ginseng* and rhizomes of *Panax japonicus* were identified as inhibitors of cyclic AMP phosphodiesterase (Nikaido et al. 1983). Saponins with a 20 (*S*)-protopanaxadiol or oleanolic acid moiety as the sapogenin were generally more inhibitory towards cyclic AMP

phosphodiesterase than saponins with a 20 (*S*)-protopanaxatriol moiety as the sapogenin. The effects of various ginsenosides on corticosterone secretion and cyclic AMP phosphodiesterase activity appeared to be parallel. Ginsenosides from ginseng leaf and stem, Rb_1, Rb_2 or Rb_3 (30 μg/ml), restored the action potentials of xanthine–xanthine oxidase-induced free radical damaged myocardiocytes to normal, indicating their antioxidative action (Jiang et al. 1992). On normal myocardial cells, Rb_1, Rb_2 and Rb_3 (20 μg/ml) inhibited the action potential and spontaneous contractility. The degrees of their inhibitory effects were found to be $Rb_1 > Rb_2 > Rb_3$. Their effects against xanthine–xanthine oxidase were basically the same.

In an animal model in-vivo, ginseng ginsenosides (GS) were shown to protect against myocardial ischaemia–reperfusion damage with concomitant increased 6-keto-PGF1 alpha and decreased lipid peroxidation (Chen 1996). In perfused rabbit lung in situ and isolated rabbit aortic rings, GS protected the pulmonary and aortic endothelium against electrolysis-induced free radical injury. The results suggested that cardiovascular protection by GS may be partly mediated by the release of NO, a potent antioxidant, and that the GS-enhanced release of NO from endothelial cells, especially from perivascular nitric oxidergic nerves in rabbit corpus cavernosum, may partly account for the aphrodisiac effect of *Panax ginseng* used in traditional Chinese medicine.

Panax ginseng was found to promote the differentiation of mouse embryonic stem cells into cardiac-like cells (Sasaki et al. 2008). During a survey of 42 compounds from the database of *P. ginseng*, they found that vitamin B_{12} (VB_{12}) and methionine were active.

Animal Studies

Administration of ginsenoside Rb_1 inhibited right ventricular hypertrophy (RVH) induced by monocrotaline in rats with some improvements of myocardial pathomorphology (Jiang et al. 2007). Rb_1 alleviated the high expressions of mRNA and/or proteins of CaN, $NFAT_3$ and $GATA_4$ from cardiocytes caused by monocrotaline. Ginseng saponins, protopanaxadiol and protopanaxatriol, significantly improved ischaemia–reperfusion injury-induced myocardial dysfunction by increasing left ventricular development pressure and time to contracture (Kim and Lee 2010). Moreover, the increases in the levels of lactate dehydrogenase (LDH), creatine kinase (CK), adenosine triphosphate (ATP) and malondialdehyde (MDA) and the decrease in the levels of GSH (reduced glutathione) were attenuated by total saponin and panaxatriol. Ginseng total saponins (GTS) inhibited endothelium cell damages induced by angiotensin II via AT1 receptor (Fang et al. 2011). The elevated plasma tumour necrosis factor-α (TNF-α) and lowered NO production induced by angiotensin II was reverted by GTS in rats. In in-vitro study, GTS reduced significantly the expressions of the NAD(P)H oxidise subunit P22phox, NF-κB and intracellular ROS production induced by angiotensin II. Ginsenoside Rg_1 administration to male rats significantly ameliorated the histopathology of common carotid artery and decreases the protein expression of proliferating cell nuclear antigen induced by endothelia rubbing (Gao et al. 2011). Rg_1 could suppress the vascular neointimal hyperplasia induced by balloon injury; the mechanism may be involved in the suppression of ERK2 signalling and related, at least partly, to the increase in mitogen-activated protein kinase phosphatase-1 (MKP-1) expression.

Ginseng ginsenoside Rg_1 alleviated rat left ventricular hypertrophy induced by abdominal aorta coarctation, and the protection appeared to be attributed partly to its inhibitory effects on calcineurin and mitogen-activated protein (MAP) kinase signalling pathways (Deng et al. 2009). A standardised ginseng extract protected rodent hearts against acute myocardial ischaemia–reperfusion injury, and the infarct size reduction effect of ginseng was associated with glucocorticoid receptor (GR)-/oestrogen receptor (ER)-mediated Akt and extracellular signal-regulated kinase (Erk) 1/2 activation in an endothelium NO synthase (NOS)-dependent manner (Zhou et al. 2011). Pretreatment of mice with compound K (20-*O*-D-glucopyranosyl-20(S)-protopanaxadiol), a novel ginseng ginsenoside

metabolite, displayed protective effects on myocardial ischaemia–reperfusion injury, partly by mediating the activation of PI3K pathway and phosphorylation of protein kinase B (Akt) and endothelial nitric oxide synthase (eNOS) activity (Tsutsumi et al. 2011). Additionally, the hearts of compound K pretreated mice showed inhibition of mitochondrial swelling induced by Ca^{2+}. Red ginseng saponin (RGS) protected rat cardiac myocytes against ischaemic injury in-vitro and in-vivo (Li et al. 2012b). RGS significantly attenuated myocardial ischaemic injury by improving cardiac systole function, partly by reducing cTnI secretion and improving cardiac diastolic function. Also, RGS attenuated the Ca^{2+} overload in cardiomyocytes and modulated the K_{ATP}, but not PI3K, signalling pathway; taken together, these mechanisms synergistically reduced infarct size.

Clinical Studies

In an 8-week, randomised, double-blind, placebo-controlled clinical trial with parallel design of 40 healthy subjects, administration of Korean red ginseng extract was found to improve blood circulation in the human body (Kang et al. 2013). Digital infrared thermal imaging showed that the temperature deviation in the whole body decreased safely in the Korean red ginseng group, which mitigated the body temperature imbalance.

Antihypertensive Activity

Kang et al. (1995) found that ginseng ginsenoside Rg_1 and ginsenoside Re from the protopanaxatriol group but not from the protopanaxadiol group enhanced the release of nitric oxide from endothelial cells and may contribute to the beneficial effect of ginseng on the cardiovascular system. The protopanaxatriol ginsenosides caused endothelium-dependent relaxation and production of cyclic GMP in the rat aorta. In subsequent study, they found that ginsenoside Rg_3 from the protopanaxatriol group caused a concentration-dependent relaxation of rat aortic rings (Kim et al. 1999c). Their results indicated ginsenoside Rg_3 to be a potent inhibitor of vascular smooth muscle tone and that this effect appeared to be due to an inhibition of Ca^{2+} influx and stimulation of K^+ efflux, possibly via activation of tetraethylammonium-sensitive K^+ channels. Ginsenoside Rg_3 was about 100-fold more potent than ginsenoside Rg_1 (Kim et al. 1999d). They further confirmed ginsenoside Rg_3 to be a major mediator of the endothelium-dependent nitric oxide-mediated relaxation in response to ginsenosides in isolated rat aorta, possibly via activation of tetraethylammonium-sensitive K^+ channels. They also demonstrated that ginsenoside Rg_3 inhibited phenylephrine-induced vascular contraction through induction of nitric oxide synthase (iNOS) which was accompanied by NF-κB activation, involving phosphorylation and degradation of I-κBα and nuclear translocation of p65 (Kim et al. 2003b). Ginseng ginsenosides Rb_1 and Re decreased cardiac contraction in adult rat ventricular myocytes partly mediated by increased nitric oxide production (Scott et al. 2001). Ginseng extract (G115) inhibited angiotensin-converting enzyme (ACE) activity, but did not affect nitric oxide production in cultured human endothelial cells from umbilical veins (HUVEC) and bovine mesenteric arteries (Persson et al. 2006). Studies showed that 20(*S*)-ginsenoside Rg_3 prevented human endothelial cell apoptosis via Akt-dependent inhibition of the mitochondrial apoptotic signalling pathway suggesting that it could help in controlling unwanted endothelial cell death at the site of vascular injury (Min et al. 2006).

Studies by Ahn et al. (2013) found that protopanaxatriol-enriched ginseng extract, TE, had the highest potency in nitric oxide production, followed by crude ginseng extract, protopanaxadiol-enriched ginseng extract and ginsenoside Rg1 in human umbilical vein endothelial cells. TE treatment resulted in rapid activation of intracellular signalling pathways, immediate linear rise of NO and increased eNOS activation. Further analysis revealed that TE, but not Rg1, resulted in AMPK phosphorylation at Thr^{172}. The results supported the premise that the multiple components of extract rich in protopanaxatriol afforded combinatorial effects in NO production and vascular endothelium relaxation via multiple signalling pathways.

Animal Studies

Following the administration of ginseng ether extract (40 mg/kg) to dogs, the heart rate and the central venous pressure decreased significantly (Lee et al. 1981). The administration of ginseng ethanol extract (40 mg/kg) caused a significant decrease in the heart rate and the mean arterial pressure. After the administration of the aqueous extract (40 mg/kg), the cardiac output, stroke volume and central venous pressure were significantly decreased, while the total peripheral resistance was significantly increased. Ginsenoside (10–100 mg/kg, i.v.) lowered blood pressure in a dose-dependent manner in rats (Kim et al. 1994). The data suggested that vascular relaxations induced by ginsenoside were mediated by the release of endothelium-derived nitric oxide which enhanced the accumulation of cGMP. Crude saponin of Korean red ginseng (50, 100 mg/kg i.v.) induced a hypotensive effect and bradycardia in a dose-dependent manner in the anesthetised rats but at 100 mg/kg induced a hypotensive effect and reflex tachycardia in the conscious rats (Jeon et al. 2000). Saponin-free fraction had no effect in the anesthetised normotensive rats. It was found that the releasing effect of nitric oxide of Korean red ginseng, like NO donor, may be partly contributed to its hypotensive effect.

Intravenous administration of garlic, onion and ginkgo extracts produced dose-dependent and reversible hypotensive and bradycardic effects in anesthetised normotensive rats (Brankovic et al. 2011). The most effective in reducing arterial blood pressure and heart rate was garlic extract.

Clinical Studies

In a study of 26 subjects with essential hypertension, 8 weeks medication with red ginseng decreased significantly 24 hour mean systolic blood pressure (Han et al. 1998). In eight subjects with white coat hypertension, no significant blood pressure change was observed. In eight subjects with white coat hypertension, no significant blood pressure change was observed. Studies by Sung et al. (2000) found that Korean red ginseng could improve vascular endothelial dysfunction in patients with hypertension possibly through increasing synthesis of nitric oxide. In a prospective, randomised, double-blind, placebo-controlled study of 30 healthy adults, therapy with *P. ginseng* extract at 200 mg extract daily increased QTc interval and decreased diastolic pressure 2 hours after ingestion in healthy adults on the first day of therapy (Caron et al. 2002).

In a double-blind, randomised, crossover design, involving 23 healthy individuals, administration of ginsenoside Rg3-enriched Korean red ginseng extract acutely lowered central and peripheral arterial pressures in healthy adults (Jovanovski et al. 2014).

Anti-inflammatory Activity

In-Vitro Studies

Panaxynol and linoleic acid were found to be major active anti-inflammatory components in ginseng root (Otsuka et al. 1981). 20(*S*)-Protopanaxatriol, one of ginsenoside metabolites, inhibited inducible nitric oxide synthase and cyclooxygenase-2 expressions through inactivation of nuclear factor-κB in RAW 264.7 macrophages stimulated with lipopolysaccharide (Oh et al. 2004a). BST204, a fermented ginseng extract, suppressed expression of cyclooxygenase-2 in murine RAW 264.7 cells by inhibition of p70 S6 kinase activation (Seo et al. 2005). The ginsenosides 20(*S*)-Rg_3, Rg_5 and Rk_1 from heat-processed ginseng selectively inhibited cyclooxygenase-2 activity (Yoo and Park 2012). Protopanaxatriol (PPT) moderately inhibited both cyclooxygenase-1 and cyclooxygenase-2. The ginsenosides 20(*R*)-Rg_3, Re and protopanaxadiol (PPD) were inactive. In the fertile egg method, ginseng chloroform extract exerted strong inhibitory activity against the formation of granulation tissue. A sterol glucoside,3-*O*-β-D-glucopyranosyl-5,22,24-stigmastatrienol, and a known sterol, 5,22-stigmastadienol), isolated from ginseng seeds, inhibited NFκB-luciferase activity, with IC_{50} values of 8.1 and 4.8 μM, respectively (Kim et al. 2013e). They also inhibited iNOS-luciferase activity in tumour necrosis factor (TNF)α-

induced HepG2 cells, with IC_{50} values of 2.2 and 2.9 μM, respectively. The dammarane triterpene saponin ginsenjilinol, ginsenoside Rf and ginsenoside Re_5 isolated from ginseng roots significantly inhibited nitric oxide production by lipopolysaccharide-activated RAW 264.7 cells in a concentration-dependent manner at concentrations of 60–200 μM with the half maximal inhibitory concentration (IC_{50}) values of 70.96 μM for ginsenjilinol, 74.14 μM for ginsenoside Rf and 79.83 μM for ginsenoside Re_5, whereas indomethacin had an IC_{50} of 63.75 μM as a positive control drug (Wang et al. 2013a). Korean red ginseng extract inhibited the expression of MCP-1 and iNOS by suppressing the activation of NADPH oxidase, a source of reactive oxygen species (ROS), and the Jak2/Stat3 pathway, which mediates the expression of inflammatory mediators, in *Helicobacter pylori*-infected gastric epithelial cells (Cho et al. 2013c). Studies found that Korean red ginseng extract (RGE) inhibited interleukin IL-1β maturation resulting from NLRP3 inflammasome activation in both in-vitro and in-vivo models (Kim et al. 2014b). In addition, RGE strongly attenuated IL-1β secretion as well as pathogen clearance via pyroptotic cell death by macrophages through inhibition of AIM2 inflammasome activation. Ginsenosides Rg_1 and Rh_3 were suggested as inhibitors of the inflammasome activation.

Animal Studies

Orally administered KRGS Korean red ginseng saponin fraction (KRGS) and its genuine ginsenosides Rg_3, Rf and Rh_2 potently inhibited the mouse passive cutaneous anaphylaxis reaction induced by IgE (Bae et al. 2006). However, when these ginsenosides were intraperitoneally administered, ginsenoside Rh_2 showed the most potent inhibition. The ginsenoside Rh_2 also most potently inhibited the beta-hexosaminidase release from RBL-2H3 cells induced by IgE with antigen. KRGS administered topically at a dose of 0.1 % suppressed ear swelling in an oxazolone-induced mouse contact dermatitis model by 38.8 %. Its constituents ginsenosides Rg_3, Rf and Rh_2 at a concentration of 0.05 % also potently suppressed mouse ear swelling by 47.5 %, 34.8 % and 49.9 % at 16 days, respectively. These ginsenosides also significantly reduced mRNA expression levels of cyclooxygenase (COX)-2, interleukin (IL)-1beta, tumour necrosis factor-alpha and interferon-gamma induced by oxazolone applied to mouse ears. The ginsenoside Rh_2 also potently inhibited COX-2 and inducible NO synthase (iNOS) protein expression in lipopolysaccharide (LPS)-stimulated RAW 264.7 cells. *P. ginseng*-head part BuOH fraction reduced the carrageenan-induced paw oedema at 3 hours after oral administration and suppressed the production of serum interleukin IL-6 in CIA mice (Lee et al. 2008a). Ginseng extract (KRG) and total saponins (GTS) inhibited LPS-induced expression of iNOS, matrix metallopeptidase 9 (MMP-9) and proinflammatory cytokines in microglial cells (Park et al. 2009a). Suppression of microglial activation by ginseng was also observed in the mouse brain inflamed by LPS. Further, KRG and GTS significantly suppressed upstream signalling molecules, NF-κB and MAP kinase activities in inflammation.

When ginsenoside Rb_1 or compound K were orally administered to 2,4,6-trinitrobenzene sulfuric acid (TNBS)-induced colitic mice, these agents inhibited colon shortening, macroscopic score and colonic thickening (Joh et al. 2011). Also, treatment with ginsenoside Rb_1 or compound K at 20 mg/kg inhibited colonic myeloperoxidase activity by 84 % and 88 %, respectively, as compared with TNBS alone, and also potently inhibited the expression of tumour necrosis factor-α, interleukin (IL)-1β and IL-6, but increased the expression of IL-10. Both ginsenoside Rb1 and compound K obstructed the TNBS-induced expressions of COX-2 and iNOS and the activation of NF-κB in mice. When ginsenoside Rb_1 or compound K was treated in LPS-induced murine peritoneal macrophages, these agents potently inhibited the expression of the proinflammatory cytokines. Ginsenoside Rb_1 and compound K also significantly inhibited the activation of interleukin 1 receptor-associated kinase-1 (IRAK-1), IKK-β, NF-κB and MAP kinases (ERK, JNK and p38). Additionally, compound K inhibited the production of proinflammatory cytokines more potently than did those of ginsenoside Rb_1.

Korean red ginseng saponin fraction (KRGS) and ginsenosides Rh2 and Rg3 were found to exert an anti-inflammatory effect in-vivo and proved to be beneficial in atopic dermatitis-like skin lesions in NC/Nga mice (Kim et al. 2011a). Topical administration of 0.1 % KRGS, 0.1 % Rh_2 and 0.1 % Rh_2 + 0.1 % Rg_3 significantly reduced the clinical skin severity scores, ear thickness and mast cell infiltration in the 2-chloro-1,3,5-trinitrobenzene (TNCB)-induced atopic dermatitis-like skin lesions in NC/Nga mice. Topical application of KRGS and its constituents significantly reduced TNCB-induced increase in ear TNF-α and IL-4 mRNA expression, but not IFN-γ mRNA expression. Among the individual ginsenosides tested, Rh_2, Rh_3 and compound K significantly inhibited LPS-induced iNOS and cytokine expressions. Ginsenoside Re (from ginseng root) treatment decreased paw and ear thickness, elevated content and NO and MDA levels induced by carrageenan in BALB/C mice (Paul et al. 2012). Ginsenoside Re inhibited secretions of inflammatory mediators such TNF α and IL-1β in RAW 264.7 macrophage. Ginsenoside Re inhibited histamine-induced scratching behaviour in mice (Jang et al. 2012). However, its inhibitory effect was significantly attenuated in mice treated with COE (mixture of cefadroxil, oxytetracycline and erythromycin). Treatment with COE also significantly lowered faecal ginsenoside Re-metabolising β-glucosidase and α-rhamnosidase activities in mice, as well as faecal metabolic activity of ginsenoside Re to ginsenoside Rh_1. Ginsenoside Rh_1 had more superior anti-scratching behavioural effect than Re and potently inhibited the expression of IL-4 and TNF-α, as well as the activation of NF-κB and c-jun activation in histamine-stimulated scratching behavioural mice.

Treatment with ginseng ginsenoside Rg_1 significantly improved survival of mice with caecal ligation and puncture-induced sepsis (Zou et al. 2013). Rg_1 administration suppressed the inflammatory response and enhanced bacterial clearance. Additionally, Rg_1 increased neutrophil counts in peritoneal cavity and inhibited lymphocyte apoptosis in the thymus and spleen.

Gastroprotective/Antiulcerogenic Activity

The 70 % methanol ginseng extracts exhibited inhibitory effects on the Shay ulcer in pylorus-ligated rats, serotonin-induced ulcer and endotoxin-induced ulcer (Matsuda and Kubo 1984). The extract also inhibited the decrease of gastric mucosal blood flow induced by serotonin and endotoxin. Ethanol extracts of the tissue-cultured ginseng and cultivated ginseng stimulated gastrointestinal propulsion in mice; the tissue-cultured ginseng also inhibited ulcer formation induced by water immersion and restraint stress and ligature of the pylorus (Suzuki et al. 1991a). In contrast, the cultivated ginseng showed no such inhibitory action. Fifty percent ethanol extracts of both cultured and cultivated ginsengs reduced gastric secretion and acid output in pylorus-ligated rats but did not affect pepsin activity (Suzuki et al. 1991b). The tissue-cultured ginseng inhibited histamine and pentagastrin-induced acid secretion in rats, but the cultivated ginseng did not. They also suppressed acid secretion induced by 2-deoxy-D-glucose and baclofen [β-(*p*-chlorophenyl)-γ-aminobutyric acid], which had been reported to stimulate gastric acid secretion via the central nervous system. However, they had no effect on acid secretion induced by vagal stimulation. The results suggested that both tissue-cultured and cultivated ginsengs may have an inhibitory effect on gastric secretion via the central nervous system.

An acidic polysaccharide fraction, GRA-4, from ginseng root, when administered from 50 to 200 mg/kg orally, inhibited gastric lesions induced by HCl/ethanol or absolute ethanol in a dose-dependent manner (1991). The cytoprotective activity of GRA-4 decreased after its treatment with periodate but not after protein digestion, indicating that the carbohydrate moiety of this acidic polysaccharide contributed to this activity. The water-soluble crude polysaccharide fraction (GL-2) from ginseng leaves and the alkaline-soluble crude polysaccharide fraction (GRA-2) from ginseng roots prevented HCl/ethanol-induced ulcerogenesis in mice potently

(Sun et al. 1992b). The most potent fraction, GL-2, was further fractionated into four polysaccharide fractions by precipitation with cethyltrimethylammonium bromide, and the weakly acidic polysaccharide fraction, GL-4, showed the most potent inhibition of gastric lesion formation. The activity of GL-4 decreased after treatment with periodate or digestion with endo-polygalacturonase, indicating that the carbohydrate moiety may contribute to the expression of the activity. Further purification of GL-4 yielded the most active purified polysaccharide, GL-4IIb1III, which prevented HCl/ethanol-induced ulcerogenesis in mice dose dependently. Oral administration of GL-4 at doses of 50–200 mg/kg inhibited the formation of the gastric lesions induced by necrotising agents such as HCl/ethanol and ethanol in a dose-dependent manner in mice and rats (Sun et al. 1992a). This protective effect was observed not only upon oral but also upon subcutaneous administration of GL-4 (50–100 mg/kg). GL-4 also inhibited the formation of gastric ulcers which were induced by water immersion stress, indomethacin or pylorus ligation. When GL-4 (100 mg/kg, p.o.) was administered into pylorus-ligated rats, both gastric acidity and pepsin activity in the gastric juice decreased significantly. An antiulcer polysaccharide (GL-BIII) was purified from ginseng leaves (Kiyohara et al. 1994).

Among ginsenoside Rg3 and its metabolites, 20(S)-protopanaxadiol and 20(R)-protopanaxadiol potently inhibited the growth of *Helicobacter pylori*, and 20(S)-ginsenoside Rh_2 inhibited H+/K + ATPase of rat stomach (Bae et al. 2002b). Acid-treated ginseng (AG) extract, fermented AG extract and protopanaxadiol potently inhibited the growth of *Helicobacter pylori* (Bae et al. 2004). Korean red ginseng extract (RGE) inhibited *Helicobacter pylori*-induced gastric inflammation in Mongolian gerbils by suppressing induction of inflammatory mediators (keratinocyte chemoattractant factor, interleukin IL-1β, iNOS), myeloperoxidase activity and lipid peroxide level in *H. pylori*-infected gastric mucosa (Bae et al. 2014).

Pretreatment of rats with ginseng extracts A and B attenuated the ethanol-induced gastric lesions compared to control group (Yeo et al. 2007). Significant induction of cytoprotective heat shock proteins HSP27 and HSP70 was found in the ginseng-administered rats, suggesting that the restoration of the proteins might contribute to the prevention of ethanol-induced gastric injuries. Ginsenoside Rd (protopanaxadiol 3,20-*O*-bisdesmoside), isolated from the flower bud, exhibited inhibitory effects on ethanol- and indomethacin-induced gastric mucosal lesions in rats (Yoshikawa et al. 2007b). Ginseng ginsenoside Re treatment of rats dose dependently prevented gastric mucosal lesion development induced by compound C48/80 treatment (Lee et al. 2014b). Increases in the activities of myeloperoxidase (MPO; an index of neutrophil infiltration) and xanthine oxidase (XO) and the content of thiobarbituric acid reactive substances (TBARS; an index of lipid peroxidation) and decreases in the contents of hexosamine (a marker of gastric mucus) and adherent mucus, which occurred in gastric mucosal tissues after C48/80 treatment, were significantly attenuated by ginsenoside Re. The elevation of Bax expression and the decrease in Bcl-2 expression after C48/80 treatment were also attenuated by ginsenoside Re. Ginsenoside Re significantly attenuated all these changes 3 hour after C48/80 treatment.

Neuroprotective/CNS Activity

Cho (2012) recently reviewed literature on the physiological and pharmacological effects of *P. ginseng* on neurodegenerative diseases and neurological disorders such as Parkinson's disease, Alzheimer's disease, Huntington's disease and amyotrophic lateral sclerosis and multiple sclerosis. Ginseng- or ginsenosides-mediated neuroprotective mechanisms covered included maintaining homeostasis and anti-inflammatory, antioxidant, antiapoptotic and immune-stimulatory activities.

In-Vitro Studies

The total ginsenoside (N-butanol extract) fraction inhibited the uptake of radioactive gamma-

aminobutyrate (GABA), glutamate (Glu), dopamine (DA), noradrenaline (NA) and serotonin (5-HT), but not the uptake of 2-deoxy- D-glucose (2-DG) and leucine (Leu) into rat brain synaptosomes (Tsang et al. 1985). Among the ginsenoside fractions investigated, fraction III which contained mainly ginsenoside Rd was the most effective in reducing the uptake of neurotransmitters. The inhibition was in the order of GABA = NA > DA > Glu > 5-HT, and this effect was concentration dependent. Similar studies indicated that ginsenoside Rc could affect neurotransmitter uptake specifically as well. Since the GABA uptake was most sensitive to the inhibitory action of these ginsenosides, it was postulated that ginseng may exert its action(s) in the central nervous system by affecting the removal of neurotransmitter substances in synaptic regions and that the GABAergic neurons may be one of the major sites of action.

Crude saponin extract of the ginseng root exerted a promoting effect on neurite extension of primary cultured neurons and also a protective effect on the distortion of neurites due to cytochalasin-B (Aiko et al. 1988). The lipophilic fraction of ginseng at a concentration of between 0.1 and 50 μg/ml induced neurite outgrowth of PC12 cells in a dose-dependent manner (Mizumaki et al. 2002). The lipophilic fraction of ginseng also induced neurite extension and promoted survival of rat cortical neurons at a concentration of between 0.025 and 1 μg/ml. It was found that ginseng lipophilic fraction exerted its neurotrophic effects via protein kinase C-dependent pathways. Liao et al. (2002) identified ginsenosides Rb1 and Rg1, extracted from ginseng root, as efficient neuroprotective agents for spinal cord neurons. These compounds dose dependently protected spinal neurons from excitotoxicity induced by glutamate and kainic acid, as well as oxidative stress induced by H_2O_2. *Panax ginseng* extract protected human neuronal SK-N-MC cells from the apoptosis induced by 2,2′,5,5′-tetrachlorobiphenyl (PCB 52) and markedly attenuated lipid peroxidation, the generation of reactive oxygen species and DNA fragmentation and markedly reduced the PCB 52 induced proteolytic cleavage of β-catenin and PARP (Lee et al. 2004b).

Ginsenoside Rg_1 exerted a survival-promoting effect on both chick and rat cerebral cortex neurons in cell cultures (Himi et al. 1989). Ginsenoside Rb_1 (GRb1) also had an effect in the rat and displayed some influence in the chick. Nerve growth factor (NGF) alone exerted no effect on both neurons, although it did potentiate the GRb1 effect on chick embryonic cerebral cortex neurons, but did not alter the GRb1 effect on rat embryonic cerebral cortex neurons. Ginsenoside Rg_3, extracted from ginseng attenuated NMDA (*N*-methyl-D-aspartate) receptor-mediated currents and NMDA-induced neurotoxicity in rat-cultured hippocampal neurons (Kim et al. 2004). Studies suggested that ginsenoside Rb_3, possibly as a non-competitive antagonist, could inhibit strychnine-sensitive glycine current at a dose-dependent manner in acutely dissociated hippocampal CA_1 neurons of young rats (Xu et al. 2005). The decrease of affinity of glycine to receptors and delay of receptor activation may be involved in Rb_3 inhibition.

Two ginseng aglycones, (20(*S*)protopanaxadiol and 20(*S*)protopanaxatriol) and ginsenoside Rh_2 (a monoglucoside of 20(*S*)protopanaxadiol), inhibited binding of [^{3}H]batrachotoxinin A-20α-benzoate ([^{3}H]BTX-B) in the mouse brain with IC_{50} values of 42 μM (20(*S*)protopanaxadiol), 79 μM (20(*S*)protopanaxatriol) and 162 μM (Rh_2) (Duan et al. 2006). It was found that 20(*S*)protopanaxadiol and the less potent inhibitor Rh_2 destabilised BTX-B-activated sodium channels through non-covalent allosteric modification of neurotoxin binding site 2. Among the nine ginsenosides tested, 20(*S*)-ginsenoside Rh_2 (20(*S*)-Rh_2) along with 20(*S*)-ginsenoside Rg_3 (20(*S*)-Rg_3) produced the highest inhibitory effect of NMDA receptors in cultured hippocampal neurons (Lee et al. 2006a). Although 20(*S*)-Rg_3 and 20(*S*)-Rh_2 selectively targeted NMDA receptors with similar potency, they produced additive effects and seemed to modulate different NMDA receptor regulatory sites. As a competitive antagonist, 20(*S*)-Rh_2 seems to inhibit the receptor via its interaction with polyamine-binding sites, and 20(*S*)-Rg_3 did so using glycine-binding sites. The data suggested that treatment of ginseng 20(*S*)-Rh_2 might be a novel preventive candidate in treating

neurodegenerative disorders. Studies by Li et al. (2007) suggested that ginsenoside Rg_2 had a neuroprotective effect in PC12 cells against glutamate-induced neurotoxicity through mechanisms related to antioxidation and antiapoptosis. Further, the inhibitory effect of ginsenoside Rg_2 against the formation of β-amyloid Aβ1-40 suggested that ginsenoside Rg_2 may also represent a potential treatment strategy for Alzheimer's disease.

López et al. (2007) found that ginsenosides from *P. ginseng* induced neuroprotection mainly through activation of antioxidant enzymes, namely, catalase, superoxide dismutase (SOD), glutathione peroxidases (GPx) and glutathione reductase (GR), and by decreasing ROS formation. Ginsenosides Rb_1, Rb_2, Re and Rg_1 were effective in reducing death of astrocytes, while Rb_1, Rb_2, Rd, Re and Rg_1 decreased ROS formation, ginsenoside Re being the most active. Exposure of astrocytes to H_2O_2 decreased the activities of antioxidant enzymes and increased ROS formation, but these adverse effects were reversed by ginseng root extract (Naval et al. 2007). Roh et al. (2010) found that Rg_3 protected rat cortical neurons against 24-hydroxycholesterol-induced cytotoxicity by inhibiting NMDA receptors through a glycine modulatory site in the cortical neurons. Ginsenosides Rf and Rg_3 were found to be active components in ginseng-mediated neuroprotection via inhibition of L-type Ca^{2+} channels in cultured rat cortical neurons (Kim et al. 2008c).

Nie et al. (2008) found that panaxydol and panaxynol protected cultured cortical neurons against Abeta25–35-induced toxicity. The antiapoptotic action of panaxydol and panaxynol was mediated via inhibition of calcium influx and free radical generation. The findings suggested the possibility that panaxydol and panaxynol may reduce neurodegeneration in Alzheimer's disease. Neopanaxadiol, a new panaxadiol first obtained from the acid hydrolysate of the total ginsenosides of *Panax ginseng*, showed neuroprotective effect against glutamate-induced neurotoxicity in primary cultures of rat cortical cells (Tao et al. 2009). Yang et al. (2010) found that panaxynol pretreatment protected cortical neurons from ischaemia-like injury from oxygen-glucose deprivation (OGD)-induced neuronal apoptosis by upregulation of HIF-1α expression and inhibition of apoptotic cascade. Ginseng water exhibited significant protective effects against 1-methyl-4-phenylpyridinium ion (MPP^+)-induced cytotoxicity in SH-SY5Y human neuroblastoma cells possibly through the suppression of ROS generation and the inhibition of mitochondria-dependent apoptotic pathway (Hu et al. 2011). The approach may be used for screening therapeutic agents for degenerative disorders such as Parkinson's disease.

Gintonin was found to activate Ca^{2+}-activated Cl-channel (CaCC) in *Xenopus* oocytes and to transiently increase intracellular free Ca^{2+} concentration ([Ca2+]I) in mouse Ehrlich ascites tumour cells (Pyo et al. 2011; Hwang et al. 2012a; Nah 2012); gintonin activated G protein-coupled lysophosphatidic acid receptors with high affinity (Shin et al. 2012; Nah 2012). Gintonin induced $[Ca^{2+}]_i$ transients in B103 rat neuroblastoma cells transfected with human LPA receptors with high affinity in the order of LPA2 > LPA5 > LPA1 > LPA3 > LPA4 (Hwang et al. 2012a). Shin et al. (2012) found that gintonin-mediated NMDA (N-methyl-D-aspartic acid) receptor-mediated ion current I (I_{NMDA}) potentiation and long-term potentiation induction in the hippocampus via the activation of LPA (lysophosphatidic acid) receptor might be responsible for ginseng-mediated improvement of memory-related brain functions. Studies by Karpagam et al. (2013) found ginseng ginsenosides CK, F1, Rh_1 and Rh_2 to be potential BACE1 inhibitors. BACE1, a β secretase candidate enzyme, had been reported to initiate the Alzheimer's disease pathogenesis via amyloid β (Aβ) peptide production serving as a potential therapeutic target. Pretreatment with ginseng ginsenoside Rb_1 activated Nrf2 (nuclear-factor-like2) pathway in cultured rat embryonic cortex-derived neural progenitor cells and led to an elevated expression of haem oxygenase-1 (Ni et al. 2014). The results demonstrated that Rb_1 displayed a potent antioxidative effect on cultured neural progenitor cells by activating Nrf2 pathway.

Animal Studies

Ginseng leaf crude saponin fraction (GF-DS-I) appeared to have CNS-depressive, neuroleptic, analgesic, hypertensive, cholinergic and histamine-like activities, while ginseng saponin GF-DS-II had CNS-depressive, neuroleptic, analgesic, hypotensive, atropine-like and papaverine-like activities in animals tested (Saito et al. 1973). These neuroleptic activities were examined and confirmed by tests on motor activity, exploratory movements, muscle tone, motor coordination, hypothermia and potentiation of CNS-depressant and pole climbing, anticonvulsant and analgesic tests. Similar effects were found for ginseng root neutral saponin fraction (Nabata et al. 1973).

Ginseng total saponin prevented the development of cocaine-induced reverse tolerance and dopamine receptor supersensitivity in mice (Kim et al. 1995b). The results suggested that ginseng total saponins may be useful for the prevention and therapy of the adverse action of cocaine. In a separate study, Tokuyama et al. (1996) showed that ginseng extract may be useful clinically for the prevention of adverse actions of methamphetamine and cocaine. A concomitant i.p. injection of ginseng extract 200 mg/kg suppressed the development of reverse tolerance, the reappearance of locomotor sensitisation and conditioned place preference induced by methamphetamine and cocaine. Administration of ginseng total saponin (GTS) prior to and during the nicotine treatment in mice inhibited not only nicotine-induced hyperactivity and reverse tolerance but also postsynaptic dopamine receptor supersensitivity in nicotine-induced reverse tolerant mice (Kim and Kim 1999; Kim et al. 1999b). Intraperitoneal injection of ginseng total saponin (GTS) prior to and during the morphine treatment in mice inhibited morphine-induced hyperactivity and conditioned place preference (Kim et al. 1998a, 1999b). GTS inhibited the development of postsynaptic dopamine receptor supersensitivity. A single-dose administration of GTS also inhibited apomorphine-induced climbing behaviour, showing the antidopaminergic action of GTS at the postsynaptic dopamine receptor.

Intraperitoneal (i.p.) pretreatment administration of ginseng ginsenosides significantly suppressed kainic acid-induced induction of heat shock protein-70 (HSP-70) in both regions of the rat hippocampus (Lee et al. 2002b). Ginseng ginsenosides were effective in protecting hippocampal CA1 and CA3 cells against kainic acid-induced neurotoxicity. Oral administration of ginseng G115 afforded robust neuroprotection against neurotoxicity in rodent models of Parkinson's disease, namely, parkinsonism-inducing neurotoxin, 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP), in mice or its toxic metabolite, 1-methyl-4-phenylpyridinium (MPP(+)), in rats (van Kampen et al. 2003). Using a novel progressive model of Parkinson's disease (PD) by chronic exposure to the dietary phytosterol glucoside, β-sitosterol β-D-glucoside (BSSG), that triggered the progressive development of neurological deficits, with behavioural and cellular features that closely approximated those observed in PD, ginseng extract was found to be a potential neuroprotective therapy for the treatment of PD. Oral administration of ginseng extract significantly reduced dopaminergic cell loss, microgliosis and accumulation of α-synuclein aggregates. Further, G115 administration fully prevented the development of locomotor deficits, in the form of reduced locomotor activity and coordination. Systemic administration of ginseng saponins (GS) produced significant protections against systemic 3-nitropropionic acid (3-NP)- and intrastriatal malonate-induced lesions in rat striatum with dose-dependent manner (Kim et al. 2005a). GS also improved significantly 3-NP-caused behavioural impairment and extended survival. GS inhibited 3-NP-induced intracellular Ca^{2+} elevations and restored 3-NP-caused mitochondrial transmembrane potential reduction in cultured rat striatal neurons. GS also prevented 3-NP-induced striatal neuronal cell deaths with dose-dependent manner; the EC_{50} was 12.6 μg/ml. Studies found that ginseng ginsenoside Rd could enhance the proliferation but not affect the differentiation of neural stem cells in rats and in-vitro (Lin et al. 2012). Ginsenoside Rd significantly increased the numbers of $BrdU^+$ and DCX^+ cells in the

hippocampal dentate gyrus. In cultured neural stem cells, ginsenoside Rd promoted the size and number of neurospheres and increased the number of $BrdU^+$ and $Ki67^+$ cells but did not affect the differentiation of neural stem cells into neurons, astrocytes and oligodendrocytes.

Orally administered acid-treated ginseng (AG) extract and ginsenoside Rh_2 potently protected the rats against ischaemia–reperfusion brain injury (Park et al. 2004b). The ginsenoside Rh_2 also inhibited prostaglandin-E2 synthesis in lipopolysaccharide-stimulated RAW 264.7 cells but showed no in-vitro antioxidant activity. Korean ginseng tea (KGT) protected rats against hypoperfusion-/reperfusion-induced brain injury; elevated lipid peroxidation (LPO) and decrease in glutathione (GSH), glutathione reductase (GR), catalase (CAT), glutathione-*S*-transferase (GST), glutathione peroxidase (GPx) and superoxide dismutase (SOD) were markedly reversed and restored to near normal levels in the groups pretreated with KGT (350 mg/kg given orally for 10 days) (Shah et al. 2005). The findings suggested Korean ginseng tea's therapeutic potential in cerebrovascular diseases (CVD) including stroke. Chronically treating the rats with ginseng saponins (orally, 5 days before intracerebroventricular β-amyloid injection and 7 days afterward) resulted in a dose-related improvement against β-amyloid-induced amnesia; a significant reversion was observed at the highest GS dose (80 mg/kg/day) (Wang et al. 2006). Pretreatment with ginseng saponins completely protected the animal against β-amyloid-induced reduction of hippocampal acetylcholine release from hippocampal slices. The results indicated that ginseng saponins pretreatment could functionally prevent the β-amyloid-induced memory loss possibly by minimising the inhibitory effect of β-amyloid on hippocampal cholinergic transmission.

Ginseng ginsenoside Rg_2 protected rats against cerebral ischaemia–reperfusion-induced impairment of neurological responses, memory and caudate-putamen neuronal apoptosis in vascular dementia (VD) rat model (Zhang et al. 2008a). Neurological responses and memory ability of the ginsenoside Rg_2 or nimodipine groups improved significantly compared with the VD group, and this was associated with antiapoptosis mechanism. The expressions of BCL-2 and HSP70 proteins was increased while those of BAX and P53 decreased after ginsenoside Rg_2 and nimodipine treatment compared with the VD group. Ginsenoside Rg_3 exhibited neuroprotective effects on homocysteine-induced hippocampal excitotoxicity in-vitro and in-vivo (Kim et al. 2007b). In rat-cultured hippocampal neurons, ginsenoside Rg_3 treatment significantly and dose dependently inhibited homocysteine-induced hippocampal cell death, with an EC_{50} value of 28.7 μM, and attenuated homocysteine-induced caspase-3 activity. In-vivo studies revealed that intracerebroventricular (i.c.v.) pre-administration of Rg_3 significantly and dose dependently reduced i.c.v. homocysteine-induced hippocampal damage in rats. The results suggested that Rg_3-induced neuroprotection against HC in rat hippocampus might be achieved via inhibition of homocysteine-mediated NMDA receptor activation.

Ginsenoside Rb_1 infusion after cerebral ischaemia significantly promoted recoveries of neurological functions at 3 and 5 days after reperfusion compared to ischaemic rats (Gao et al. 2010). It was found that regulation of the expressions of brain-derived neurotrophic factor (BDNF) and caspase-3 may be involved in GRb1-induced neuroprotection against cerebral ischaemia. Ginsenoside Rd protected adult male Sprague-Dawley rats and cultured cortical neurons against okadaic acid-induced neurotoxicity and tau hyperphosphorylation by enhancing activities of protein phosphatase 2A (Li et al. 2011). In animal tests including tail suspension test, forced swimming test and rat olfactory bulbectomy depression model, it demonstrated antidepressant-like activity as potent as fluoxetine. It significantly reduced brain oxidative stress and downregulated serum corticosterone concentration in bulbectomy animals.

Studies by Shim et al. (2000) suggested that ginseng total saponin (GTS) may have an inhibitory action against nicotine-induced dopamine release in the brain nucleus accumbens (NA) of freely moving rats and tyrosine hydroxylase mRNA expression in the ventral tegmental area region. GTS may exert a potentiative effect on

both c-fos and c-jun mRNA expressions at the nucleus accumbens region through inhibiting the release of dopamine in the nucleus accumbens. Studies suggested that intraperitoneal injections of ginseng total saponins could improve neurological deficits after focal cerebral ischaemia in rats by inducing endogenous neural stem cells activation and thereby enhancing adult central nervous system regeneration (Zheng et al. 2011). Hwang et al. (2012b) demonstrated that gintonin, a novel lysophosphatidic acid (LPA) receptor-activating ligand from ginseng, mediated the promotion of non-amyloidogenic processing to stimulate soluble sAβPPα (amyloid-β protein precursors alpha) release to restore brain function in mice with Alzheimer's disease. Gintonin promoted sAβPPα release in a concentration- and time-dependent manner. Moreover, in a transgenic mouse Alzheimer's disease D model, long-term oral administration of gintonin attenuated amyloid plaque deposition as well as short- and long-term memory impairment. Gintonin could be a useful agent for AD prevention or therapy.

Pre-administration of ginsenoside Rd protected mice against ischaemic brain damage induced by middle cerebral artery occlusion (MCAO) (Ye et al. 2011a). Rd at the doses of 10–50 mg/kg significantly reduced both cortical and striatal infarct volumes. This protection was associated with an improvement in neurological function and was sustained for at least 2 weeks after the insult. Rd significantly suppressed the accumulations of DNA, protein and lipid peroxidation products at 24 hour post-ischaemia. Rd also protected mitochondria at 4 and 24 hours after reperfusion. Furthermore, Rd partly enhanced endogenous antioxidant activities following MCAO. Ginsenoside Rd at the dose of 10–50 mg/kg significantly reduced the infarct volume and improved the long-term neurological outcome up to 6 weeks after focal cerebral ischaemia in rats (Ye et al. 2011b). Its neuroprotective activity may involve early free radicals scavenging pathway and a late anti-inflammatory effect.

Pretreatment of ginsenoside Rb_1 protected against cerebral ischaemic damage induced by middle cerebral artery occlusion and reperfusion in rats (Zhu et al. 2012). The results indicated that suppression of local inflammation after cerebral ischaemia might be one mechanism that contributed to the neuroprotection of ginsenoside Rb_1. In-vivo studies found that ginsenoside 20(*R*)-Rg_3 afforded significant neuroprotective effect in rats against focal cerebral ischaemic injury by markedly reducing cerebral infarct volumes and degrading infarct rate and improving behaviour of the animals (He et al. 2012). The results also suggested that 20(*R*)-Rg_3 (10 and 20 mg/kg) could significantly suppress the expressions of calpain I and caspase-3 mRNA.

Clinical Studies

Ginseng exhibited beneficial effects on γ-aminobutyric acid $(GABA)_A$ receptor-related anxiety and sleep disorders (Lee et al. 2013a). Its ginsenoside RG_3 also induced $GABA_A$ receptor activation. The results indicated that Rg_3-induced $GABA_A$ receptor activation via the γ_2 subunit and I_{GABA} enhancement by Rg_3 might be one of the molecular bases of ginseng effects on $GABA_A$ receptor. In a study of young male healthy volunteers (from 15 to 37 years old), ingestion of red ginseng extract three times daily for 7 days could improve the quality of sleep, thus having beneficial effects on sleep-disturbed subjects (Han et al. 2013). Total wake time was significantly reduced and sleep efficacy was increased, although slow-wave sleep stage 1 (N1) was reduced and non-rapid eye movement (REM) sleep was increased after ginseng administration.

Hepatoprotective Activity

Stem heat-processed ginseng containing ginsenosides Rg_3, Rk_1 and Rg_5 as its main ginsenoside components protected rats against lipopolysaccharide (LPS)-induced liver injury (Kang et al. 2007). LPS-elevated hepatic mitochondrial thiobarbituric acid reactive substance (TBA-RS) level was significantly lowered by 15 consecutive days of ginseng administrations. Additionally, upregulated hepatic inducible nitric oxide synthase and haem oxygenase 1 levels in LPS-treated

control rats were significantly lowered and increased, respectively, by 100 mg/kg body weight/day of ginseng administration.

Wild ginseng was found to be efficacious in protecting rats against benzo[α]pyrene (BP)-induced hepatotoxicity (Gum et al. 2007). Pretreatment with wild ginseng for 4 weeks completely attenuated BP-induced increases in the alanine aminotransferase (ALT), aspartate aminotransferase (AST) and lipid peroxidation (LPO) levels and reversed BP-induced reduction of glutathione (GSH) content and glutathione S-transferase (GST) activity. Moreover, glutathione S-transferase alpha 2 (GSTA2), glutathione S-transferase alpha 3 (GSTA3) and glutathione S-transferase mu *2* (GSTM2) gene expressions were significantly increased by wild ginseng through the nuclear factor E2-related factor 2 (Nrf2)/antioxidant-responsive element pathway for enzyme induction. Wild ginseng moderately inhibited BP-induced CYP1A1 gene expression.

Spirulina platensis and *Panax ginseng* exhibited protective effect on cadmium-induced oxidative stress and hepatotoxicity in adult female Wistar albino rats (Karadeniz et al. 2009a). Both treatments markedly reduced lipid peroxidation and increased the endogenous antioxidants levels. *Panax ginseng* pretreatment of rats elicited protective effects against carbon tetrachloride toxicity as evidenced by decreases of tissue concentrations of oxidative stress markers (malondialdehyde and NO) and the reduction of CCL_4-induced antioxidant depletion and by histological attenuation of CCL_4-induced liver (cell degenerescence and fibrosis) injury (Karadeniz et al. 2009b). Ginseng treatment in combination with cadmium chloride in Swiss albino mice was protective against cadmium-induced hepatic injuries, significantly decreasing LPO, glutamic oxaloacetic transaminase (GOT) and glutamic pyruvic transaminase (GPT) and augmented GSH and serum alkaline phosphatase (Shukla and Kumar 2009). Ginsan effectively prevented carbon tetrachloride (CCl_4)-induced liver injury in BALB/c mice (Shim et al. 2010). The hepatoprotective effect of ginsan was attributed mainly through downregulation of oxidative stress induction of antioxidant protein contents, such as superoxide dismutase (SOD), catalase and glutathione peroxidase (GPX), as well as restoration of the hepatic GSH concentration and suppression of proinflammatory cytokines (IL-1β, IFN-γ) and chemokines (MCP-1, MIP-2β, KC). *Panax ginseng* treatment may play a protective role against carbon tetrachloride (CCl_4)-induced acute hepatotoxicity in rats (Karakus et al. 2011). Park et al. (2012) found that Korean red ginseng and its primary ginsenosides (Rg_3 and Rh_2) inhibited ethanol-induced oxidative injury by suppression of the mitogen-activated protein kinase (MAPK) pathway in mouse hepatocytes (TIB-73) cells. Pretreatment of rats with ginseng attenuated the elevated serum enzyme activities of liver and some biochemical parameters induced by CCL_4 challenge. Two months oral administration of Korean red ginseng or urushiol (*Rhus vernicifera*) treatment improved lipid profiles in rats with nonalcoholic fatty liver disease (NAFLD) (Hong et al. 2013). Both treatments significantly increased natural killer cell activity in NAFLD rats and inhibited steatohepatitis in OLETF (Otsuka Long-Evans Tokushima Fatty) rats. Administration of ginseng essence (comprising *Panax quinquefolius*, *Panax ginseng*, *Nelumbo nucifera* and *Lilium longiflorum*) ameliorated oxidative stress and inflammation in CCL_4-induced rats and improved liver function and abnormal metabolism of lipid (Weng et al. 2014). Additionally, ginseng essence could inhibit the activation of hepatic stellate cells by elevating the activities of antioxidative enzymes and the content of antioxidant, and also, it could ameliorate liver fibrosis.

Antiobesity Activity

The petroleum ether extract of *Panax ginseng* showed a significant inhibition of the diacylglycerol acyltransferase (DGAT) enzyme from rat liver microsomes (Lee et al. 2004d). DGAT is a key enzyme in the synthesis of triglycerides for the formation of adipose tissues. Bioactivity-guided fractionation led to the isolation of two new polyacetylenic compounds, (9*R*,*10*S)-epoxyheptadecan-4,6-diyn-3-one(1)and1-methoxy-(9*R*,10*S*)-epoxyheptadecan-4,6-diyn-3-one (2), and

the IC_{50} values were 9 μg/mL for (1) and 32 μg/mL for (2). In-vitro studies showed that the less polar ginsenosides, particularly ginsenoside Rg3, effectively reduced lipid accumulation in 3T3-L1 adipocytes, indicating that ginsenoside Rg_3 could be developed as an antiobesity treatment (Kim et al. 2009b). Hwang et al. (2009) found that the antiobesity effect of red ginseng rich constituent, ginsenoside Rg_3, involved the AMP-activated protein kinase (AMPK) signalling pathway and PPAR-gamma inhibition. Earlier, Hwang et al. (2007) found that ginsenoside Rh_2 was the most effective candidate for preventing metabolic disorders such as obesity and that it acted via the AMPK signalling pathway. Studies by Siraj et al. (2014) found that ginseng ginsenoside F_2 treatment with different doses reduced the level of lipid accumulated by obesity cell line 3T3-L1 adipocyte line during adipogenesis. There was a reduction in peroxisome proliferator-activated receptor gamma (PPARγ) and perilipin gene expression levels compared to that of differentiated adipocytes without any treatment.

Otsuka Long-Evans Tokushima Fatty rats, an obese insulin-resistant rat, treated with ginsan, a vinegar ginseng extract rich in ginsenoside Rg_3, had lower fasting and postprandial glucose concentrations and plasma insulin and improved glucose tolerance compared with vehicle-treated rats (Lim et al. 2009). These beneficial effects on body weight and glucose homeostasis were associated with alteration of expression of genes, glucose transporter 4, peroxisome proliferator-activated receptor γ and adenosine monophosphate-activated protein kinase, involved in glucose and fatty acid metabolism. Chronic administration of Korean red ginseng (KRG) reduced weight gain and visceral fat mass in the early period without altering food intake of Otsuka Long-Evans Tokushima fatty rats (Lee et al. 2009a). The KRG-treated fatty rats showed improved insulin sensitivity and significantly preserved glucose tolerance compared with untreated control animals up to 50 weeks of age, implying that KRG attenuated the development of overt diabetes. KRG promoted fatty acid oxidation by the activation of adenosine monophosphate-activated protein kinase (AMPK) and phosphorylation of acetyl-coenzyme A carboxylase in skeletal muscle and cultured C2C12 muscle cells. Increased expression of peroxisome proliferator-activated receptor-γ coactivator-1α, nuclear respiratory factor-1, cytochrome *c*, cytochrome *c* oxidase-4 and glucose transporter 4 by KRG treatment indicated that activated AMPK also enhanced mitochondrial biogenesis and glucose utilisation in skeletal muscle. Ginseng was found to reduce body weight, adipose tissue mass and adipocyte size, but not food intake in high-fat diet-fed obese mice (Lee et al. 2013c). Ginseng decreased blood vessel density and MMP activities in adipose tissue. The expression of angiogenic factors (VEGF-A and FGF-2), (MMP-2 and MMP-9) and their inhibitors TSP-1, TIMP-1 and TIMP-2) in adipose tissue was markedly modulated by ginseng. The findings indicated that ginseng may prevent adipose tissue growth and obesity by inhibiting adipose tissue angiogenesis.

In the study of ten obese middle-aged Korean women, consumption of ginseng extract for 8 weeks exerted a weight loss effect and slight effects on gut microbiota in all participants (Song et al. 2014). The antiobesity effects of ginseng differed depending on the composition of gut microbiota prior to ginseng intake.

Analgesic/Antinociceptive Activity

Morphine-induced antinociception was prevented by pretreatment with ginseng total saponins in the tail-pinch and tail-flick tests carried out in mice (Kim et al. 1992). U-50,488H-induced antinociception was prevented by ginseng total saponins in the tail-flick but not in the tail-pinch test. It was found that antagonism of U-50,488H-induced antinociception by ginseng total saponins was dependent on serotonergic mechanisms. Later studies by Nemmani and Ramarao (2002) found that acute and chronic administration of ginseng total saponin (GTS) potentiated the U-50,488H (U 50)-induced analgesia in U50-naive mice. The potentiating effect of GTS on U50-induced analgesia may be partially responsible in the inhibition of tolerance to U50-induced analgesia in mice. Systemic administration of ginsenoside

Rf (Rf) in mice elicited dose-dependent antinociception using two separate assays of tonic pain: in the acetic acid abdominal constriction test, the ED_{50} was 56 mg/kg, a concentration similar to those reported for aspirin and acetaminophen in the same assay; in the tonic phase of the biphasic formalin test, the ED_{50} was 129 mg/kg (Mogil et al. 1998). Rf failed to affect nociception measured in three assays of acute pain: the acute phase of the formalin test and the thermal (49 °C) tail-flick and increasing-temperature (3 °C/minute) hot-plate tests. Further it was found unlikely that Ca^{2+} channel inhibition on primary sensory neurons could fully explain the behavioural antinociception demonstrated for Rf.

Studies suggested that ginseng ginsenosides had antinociceptive activity in the formalin test, and this effect was due to blocking of SP-induced nociceptive information to postsynaptic site(s) at the spinal level (Yoon et al. 1998). Pretreatment of mice with ginsenosides by intrathecal injection induced the inhibition of biting and licking of hind paw injected with 1 % formalin with dose-dependent manner. The ED_{50} was 23 μg/mouse for acute phase and 15 μg/mouse for tonic phase. In subsequent animal studies, they found that ginsenosides produced antinociceptive effects through their action at the spinal and/or supraspinal site(s), not at nociceptors in the periphery (Nah et al. 2000). In addition, their results suggested that the antinociceptive effects were not mediated by opioid receptors.

Application of ginseng total saponins dose dependently suppressed Ca^{2+} channel currents in rat sensory neurons (Rhim et al. 2002). Also, ginseng total saponins could modulate L-, N- and P-type currents. The co-application of ginseng total saponins and the μ-opioid receptor agonist, d-Ala^2, *N*-$MePhe^4$ and Gly^5-ol-enkephalin (DAMGO), produced nonadditive effects in most cells tested, and each effect was significantly relieved by a depolarising prepulse. The results suggested that the modulation of Ca^{2+} channels by ginseng total saponins, in particular by ginsenoside Rg_3, could be part of the pharmacological basis of ginseng-mediated antinociception.

P. ginseng-head part BuOH fraction (PGHB) was safe in acute toxicity (LD_{50} > 5,000 mg/kg) and inhibited the partially acetic acid-induced writhes (approximately 32 %) in mice (Lee et al. 2008a). Ginseng extract (500 mg/kg) inhibited the acetic acid-induced extravasation of Evan's blue dye in mice and was similar to the suppressive effect of ibuprofen as a positive control drug. A polyacetylenic compound, (9R,10S)-epoxyheptadecan-4,6-diyn-3-one (EHD), isolated from ginseng root extract inhibited Na^+ currents in primary sensory neurons; EHD by inhibiting Na+ currents may contribute to the ginseng analgesia (Choi et al. 2008). Four glycoproteins isolated from ginseng root exhibited significant analgesic activities (Wang et al. 2013b). The glycoproteins in which protein content was the highest (73.04 %) displayed dose-dependent analgesic effect. In writhing test, the glycoproteins significantly inhibited writhes at the dose of 20 mg/kg by intraperitoneal injection. In hot-plate test, only the dose of 20 mg/kg prolonged the hot-plate latency. In the locomotor activity test, the glycoproteins significantly decreased motility counts at the dose of 20 and 40 mg/kg. Intraperitoneal administration of ginseng total saponins before or after surgery induced antihyperalgesic effects in a rat model of incisional pain (Kim et al. 2014d). The effects on mechanical hyperalgesia may be associated with anti-inflammatory cytokines and *N*-methyl-D-aspartate (NMDA) signalling.

In a 12-week, randomised, double-blind, controlled clinical trial of 38 patients with fibromyalgia, VAS (visual analogue scale) rating revealed a reduction in pain in the *P. ginseng* group, an improvement in fatigue and an improvement in sleep; with respect to baseline characteristics, there were no differences between the ginseng, amitriptyline and placebo groups (Braz et al. 2013). With respect to anxiety, improvements occurred in the *P. ginseng* group compared to baseline; however, amitriptyline treatment resulted in significantly greater improvements.

Antidepressant/Anxiolytic Activity

White and red varieties of ginseng (20 and 50 mg/kg) showed positive results when tested against several paradigms of experimental anxiety (Bhattacharya and Mitra 1991). Both were effec-

tive in the open-field and elevated plus maze tests and reduced conflict behaviour in thirsty rats and footshock-induced fighting in paired mice. Ginseng also attenuated pentylenetetrazole-induced decrease in rat brain MAO activity, confirming its anxiolytic activity since this has been proposed to be an endogenous marker for anxiety. Park et al. (2005b) found that the anxiolytic potential of sun ginseng (heat-processed ginseng at higher temperature) was stronger than that of red ginseng (steamed raw ginseng at 98–100 °C) by significantly increasing the number of open arms entries and the time spent on the open arms in the elevated plus maze model. Ginseng saponins were suggested to play an important role in the anxiolytic effects of ginseng.

The acidic polysaccharide portion of the plant (WGPA), containing arabinogalactan-, type-I rhamnogalacturonan (RG-I)- and homogalacturonan (HG)-rich pectins exhibited antidepressant activity in mice (Wang et al. 2010a). At 100 mg/kg (but not the 200 mg/kg) it significantly reduced immobility time in the forced swim test, and both doses significantly increased social interactions and decreased aggressive behaviours in mice. It had no effects on spontaneous activity or behaviour in the elevated plus maze test.

Ginseng powder and crude saponin ginseng fraction significantly increased the frequency and duration of open arm entries of mice in the elevated plus maze test (Carr et al. 2006). Among the three types of pure ginsenoside (ginsenosides Rb_1, Rg_1 and Ro), only ginsenoside Rb_1 significantly increased both the frequency and duration of open arm entries. The results clearly implicated ginsenoside Rb_1 to be one of the active anxiolytic components of ginseng root.

Antiviral Activity

Panaxagin from ginseng root displayed an inhibitory activity against human immunodeficiency virus reverse transcriptase, and succinylation augmented this activity (Ng and Wang 2001). Polyacetyleneginsenoside Ro from ginseng root was found to inhibit the replication of human immunodeficiency virus type 1 (HIV-1) with an IC_{50} value of 13.4 μg/mL (11.1 μM) (Zhang et al. 2002). Triterpenoids (20*R*)-20,25-epoxydammaran-2-en-6α,12β-diol; (20*R*)-20,25-epoxy-3-methyl-28-nordammaran-2-en-6α,12β-diol; isodehydroprotopanaxatriol; and oleanolic acid showed inhibitory activity against HIV-1 protease with IC_{50} of 10.5, 10.3, 12.3 and 6.3 μM, respectively (Wei et al. 2009). Mice and ferrets fed with a 60-day diet containing red ginseng could be protected from lethal infections by highly pathogenic H5N1 influenza virus (survival rate of up to 45 % and 40 %, respectively) (Park et al. 2014). Interferon-α and interferon-γ antiviral cytokines were significantly induced in the lungs of mice fed with red ginseng, compared to mice fed with an unsupplemented diet.

Studies in human immunodeficiency virus (HIV)-1-infected patients showed that a combined therapy of Korean red ginseng and zidovudine for a prolonged period maintained $CD4^+$ T cell counts from 239 to 234/μl, whereas in patients treated with zidovudine alone, $CD4^+$ T cell counts decreased from 272 to 146/μl (Cho et al. 2001). This combined effect might be indirectly associated with delayed development of resistance mutation to zidovudine by red ginseng intake.

Two ginseng pectic polysaccharides, named as GP50-dHR and GP50-eHR, rescued cell viability from rotavirus infection dose dependently with IC_{50} values of 15 and 10 μg/mL, respectively, by inhibiting rotavirus attachment to cells (Baek et al. 2010). The results suggested ginseng polysaccharides to be viable therapeutic options for rotavirus diarrhoea.

Antibacterial and Antifungal Activity

Panaxagin from ginseng root exhibited ribonuclease activity towards yeast transfer RNA, translation-inhibitory activity in a rabbit reticulocyte lysate system and antifungal activity against fungi including *Coprinus comatus* and *Fusarium oxysporum*, but not against *Rhizoctonia solani* (Ng and Wang 2001). In-vitro and in-vivo studies found that ginseng polysaccharide (GP) possessed anti-septicaemic activity against sepsis

caused by *Staphylococcus aureus* (Lim et al. 2002). In-vitro GP showed potent phagocytic activity and stimulated production of TNF-α by macrophage with 96 % lysis of murine fibrosarcoma L 929 cells. GP also stimulated production of IL-1 and IL-6 by stimulation of macrophage. The low mortality of GP-treated (0.025 mg/kg) infected mice was associated with decreased bacterial content in the blood. Nitric oxide production in *S. aureus*-infected mice whose macrophage was stimulated by GP increased approximately four times than the untreated *S. aureus*-infected group at 24 and 48 hours incubation. Combined treatment with GP (0.025 mg/kg body weight) and vancomycin (10 mg/kg B.W.) resulted in 100 % survival of the animals, whereas only 67 % or 50 % of the animals survived, respectively, when treated with GP or vancomycin alone.

Ginseng treatment of mouse with chronic *Pseudomonas aeruginosa* lung infection significantly lowered mortality (Song et al. 2003). The lung cells from the ginseng-treated group produced more interferon-gamma (IFN-γ) and tumour necrosis factor-alpha (TNF-α) but less interleukin 4 (IL-4). The ginseng-treated splenocytes produced more TNF-α and IFN-γ than the control spleen cells. Furthermore, a significantly milder lung pathology and faster bacterial clearance were observed. The results indicated a Th1-like immune response in the mice with *P. aeruginosa* lung infection after 7 days of ginseng treatment. Studies showed that administration of ginsenoside Rg_1 to mice intraperitoneally before intravenous challenge with live *Candida albicans* yeast cells protected them from experimental disseminated candidiasis (Lee and Han 2006). The protection was found to be mediated by Th1-type differentiation of CD4+ T cell. Also, ginsenoside Rg_1 inhibited in-vitro growth of *C. albicans* as tested by the agar diffusion susceptibility method. Ginsenoside Rd was found to have immunoadjuvant ability to induce *Candida albicans* surface mannan extract (CASM) to produce a protective antibody in mice (Han and Rhew 2013). This protected mice against disseminated candidiasis by eliciting higher titres of Th1-type antibody and a Th1-dominant immune response.

PG-F2, an acidic polysaccharide with high uronic acid content purified from the root of *Panax ginseng*, inhibited the adhesion of *Helicobacter pylori* to gastric epithelial cells and the ability of *Porphyromonas gingivalis* to agglutinate erythrocytes (Lee et al. 2004a). PG-F2 also exhibited its anti-adhesive effects against *Actinobacillus actinomycetemcomitans*, *Propionibacterium acnes* and *Staphylococcus aureus*. The minimum inhibitory concentrations (MIC) were found to be in a range of 0.25–0.5 mg/mL (Lee et al. 2006a). However, PG-F2 exhibited no inhibitory effects against *Lactobacillus acidophilus*, *Escherichia coli* or *Staphylococcus epidermidis*. Limited hydrolysis of PG-F2 via treatment with pectinase yielded an oligosaccharide fraction, with activity comparable to the precursor PG-F2 (the MIC of ca. 0.01 mg/mL against *H. pylori* and *P. gingivalis*). Polysaccharides PG-F2, a pectin-type polysaccharide, and PG-HMW, an arabinogalactan from *Panax ginseng*, demonstrated strong anti-adhesive activities against oral and skin pathogens to host cell lines in a dose-dependent manner from 0.1 to 2.0 mg/ml (Lee et al. 2009b). PG-F2 and PG-HMW might have a selective anti-adhesive effect against certain pathogenic bacteria without adverse effects on commensal bacteria. Polyacetylene compounds, dihydropanaxacol, panaxacol 1-hydroxydihydropanaxacol and 17-hydroxypanaxacol, from ginseng hairy roots, exhibited antimicrobial activity in-vitro against *Staphylococcus aureus*, *Bacillus subtilis*, *Cryptococcus neoformans* and *Aspergillus fumigatus* (Fukuyama et al. 2012).

Radioprotective Activity

A single intraperitoneal injection of partially purified ginseng extract after X-irradiation of 650–675 R significantly increased the 30-day survival ratio in mice (Yonezawa 1976). Oral administration of a ginseng extract resulted in an increase of the number of mitotic cells both in myeloid and erythroid cells. Intraperitoneal injection of the extract also increased the rate of syntheses of serum albumin and gamma globulin as well as DNA, RNA, protein and lipid syntheses in bone marrow cells. Two fractions of ginseng

extract, namely, CM-A and CM-B, were significantly efficacious at 5 % level and 0.1 % level, respectively, with the doses proportional to their yields (Yonezawa et al. 1981). CM-B (free of saponins) was separated into three fractions: G-I (0.44 mg per animal) and G-III (0.84 mg, calculated dose) were significantly efficacious, but G-II (0.47 mg) was not. Radiation protection from bone marrow death by a single injection (intraperitoneal and intravenous) of partially purified ginseng extract after whole-body X-irradiation was confirmed in JCL-ICR mice (Takeda et al. 1981). Stimulated recovery by the extract was also observed in thrombocyte and erythrocyte counts, while the extract did not markedly affect recovery of leucocyte counts. The extract also increased 30-day survival ratio of splenectomised mice. Recovery of thrombocyte counts after exposure was assumed one of the most important factors for restoration of bone marrow death. A thermostable fraction of the ginseng extract protected mice (male) irradiated with 720 R of X-rays and rats (male) irradiated with 825 R with the dose about 6 mg per 100 g of body weight (Takeda et al. 1982). The fraction also protected guinea pigs, both female and male, irradiated with 325 R with the dose of about 80 mg per 300 g of body weight. Comparison of stimulated recovery by the thermostable fraction of the ginseng extract among the three blood cell counts showed that restoring action was the most marked on thrombocyte counts, commonly in the three species of the animals. A single postirradiation injection of the thermostable fraction of a ginseng extract enhanced the recoveries of the numbers of both blood-forming stem cells (10 days CFUs) and megakaryocytes in bone marrow of irradiated mice (Yonezawa et al. 1985). It also protected haemorrhaging tendency of X-irradiated mice determined by a quantitative measurement of occult blood appearance in daily faeces. The present study and their previous findings suggested that ginseng protected the irradiated animals from bone marrow death by stimulating thrombopoietic hematogenesis (CFUs, megakaryocytes and thrombocytes) and finally preventing haemorrhage. Zhang et al. (1987) found that water-soluble extract of whole ginseng gave the best protection against gamma radiation in C3H mice. The isolated protein and carbohydrate fractions gave less protection, while the saponin fraction did not. In further studies, they found that the water fraction and alkaloid fraction of *Panax ginseng* may reduce cell damage caused by gamma-rays, especially damage to DNA molecules, and play a role in the repair or regeneration process of damaged cells (Kim et al. 1993). Further, they found that ginseng administration before irradiation protected the jejunal crypts, increased the formation of endogenous spleen colony and reduced the frequency of radiation-induced apoptosis (Kim et al. 2001). Diethyldithiocarbamate (DCC) afforded similar radioprotective effects but showed no significant modifying effects on the formation of endogenous spleen colony. Also, they found that the lipophilic nonpolar compounds (fraction 1), lipophilic-acidic compounds (fraction 2), free sugars (fraction 7) and saponin compounds (fraction 8) of ginseng extract might have a major radioprotective effect.

Ginsan, the polysaccharide extracted from ginseng roots, and amifostine did not alter the frequency of micronucleated polychromatic erythrocytes (MNPCE) of control mice, showing that they were non-mutagenic per se; gamma irradiation induced a statistically significant increase of MNPCE and decrease of PCE/NCE ratio compared to control group (Ivanova et al. 2006). However, ginsan applied 30 minutes before or 15 minutes after irradiation reduced MNPCE in a dose-dependent manner. Amifostine (200 mg/kg b.w.) did not reduce radiation-induced MNPCE, but stimulated erythropoiesis, when administered before irradiation. Based on the above results, the radioprotective effect of ginsan can be partially attributed to the reduction of radiation-induced genotoxicity.

Ginsan (acidic polysaccharide of *Panax ginseng* roots) pretreatment of bone marrow cells (BMs) significantly increased the viability of BMs against gamma radiation and increased production of interleukin IL-12, a major cytokine for immune responses (Kim et al. 2007a). Moreover, ginsan-treated mice had a larger number of BMs after gamma radiation than the control mice. The results suggested that ginsan may be a good candidate radioprotective agent for bone marrow

cells. Ginsan protected mice from gamma radiation-induced damage of the small intestine (Park et al. 2011a). Ginsan treatment caused the lengthening of villi and a numerical increase of crypt cells in the small intestine at 3.5 days after 7 Gy irradiation compared to irradiated, non-treated controls. Additionally, ginsan significantly inhibited irradiation-induced apoptosis by decreasing the amount of pro-apoptotic p53 and Bax as well as augmenting that of antiapoptotic Bcl-2 at 24 hours after irradiation. Further they found that ginseng acidic polysaccharide (APG) protected mouse small intestine from irradiation-induced apoptosis through inhibition of the p53-dependent pathway and the mitochondria/caspase pathway (Bing et al. 2014).

Treatment with ginsenoside Rd before γ-irradiation inhibited irradiation-induced apoptosis in murine intestinal epithelial IEC-6 cells (Tamura et al. 2008). Administration of Rd after irradiation also inhibited apoptosis in these cells. It was found that ginsenoside Rd protects and rescues rat intestinal epithelial cells from irradiation-induced apoptosis through a pathway requiring activation of PI3K/Akt, inactivation of MEK and also inhibition of a mitochondria/caspase pathway.

Studies suggested that red ginseng saponin fraction could be considered and developed for use as an effective radioprotective agent with minimal adverse effects (Lee et al. 2014c). Ginseng fraction strongly suppressed ionising radiation (IR)-enhanced and lipopolysaccharide (LPS)-induced proinflammatory responses such as nitric oxide (NO) production ($IC_{50} = 5.1$ μM) and interleukin 1β levels. It was found to exert its radioprotective effects by inhibition of a signalling cascade that activated checkpoint kinase 2-nuclear factor-κB. In addition, it strongly inhibited IR-enhanced LPS-induced expression of hemoxyganase-1.

Angiogenic Activity

Results of in-vitro studies in human umbilical vein endothelial cell (HUVEC) and in-vivo studies in mouse suggested that ginsenosides Rg_1 and Re could be a novel group of nonpeptide angiogenic agents with a superior stability and may be used for the management of tissue regeneration (Yu et al. 2007). It was found in-vitro that HUVEC proliferation, migration in a Transwell plate and tube formation on Matrigel were all significantly enhanced in the presence of basic fibroblast growth factor (bFGF), Rg_1 or Re. However, after being treated at different temperatures, pH or solvent species, the remaining activity of bFGF on HUVEC behaviours reduced significantly, but the activities of Rg_1 and Re remained unchanged throughout the entire course of the study. The in-vivo results observed on day 7 after implantation showed that the blank control (Matrigel alone) was slightly vascularised. In contrast, the density of neovessels in the Matrigel plug mixed with bFGF, Rg_1 or Re was significantly enhanced. However, after being treated, the density of neovessels was significantly reduced in the Matrigel plug mixed with bFGF, while those of Rg_1 and Re remained unchanged. Lin et al. (2008) found that the stimulating effect of Rg_1 HUVECs proliferation remained unchanged after dissolved for 30 days in culture medium at 37 °C when compared with the effect of bFGF. One week after implantation in transgenic mice, bFGF or Rg_1 mixed in Matrigel plug significantly enhanced angiogenesis; however, at 6 weeks a significant decrease in angiogenic effect was observed in Matrigel with bFGF, but not in Matrigel with Rg_1. The results confirmed that Rg_1 could be used in tissue engineering.

Spasmolytic Activity

All ginseng saponins diminished acetylcholine-induced contraction of the isolated ileum of the guinea pig, but high concentrations of Rb_2 caused contraction of the ileum by itself (Kaku et al. 1975). Both ginseng total saponins (GTS) and its constituents, protopanaxatriol saponins (PT), inhibited the electrically evoked contractions of guinea pig ileum (GPI) in a concentration-dependent manner in a range of 1–100 μg/ml, and this effect was irreversible at high concentrations of the saponins (Watanabe et al. 1988). Protopanaxadiol saponins (PD) had a transient and weak effect. In contrast, in mouse vas deferens (MVD), the contractions were increased by

PT and PD; however, GTS was almost without effect. The inhibitory effect of morphine was arithmetically increased by pretreatment with 100 μg/ml of these saponins in guinea pig ileum preparations, while the inhibitory effect of the contractions was potentiated in MVD preparations. Neither the inhibition of contractions in the guinea pig ileum preparation nor the facilitation of contractions in the MVD preparation by these ginseng saponins was reversed by naloxone, in contrast to naloxone antagonism of morphine-induced contractions in both preparations. GTS and PT caused a dose-dependent inhibition of $BaCl_2$-induced contraction of guinea pig ileum. It was concluded that the mechanism on the inhibitory or facilitated effect of ginseng saponins on electrically evoked contractions in guinea pig ileum and mouse vas deferens preparations may be based on the direct action of the saponins on smooth muscles preparations and not on the effect of opioids.

Anti-glaucoma Activity

Ginseng was found to have parasympathomimetic activity (Takatori et al. 1963). In a prospective, randomised, placebo-controlled, double-masked crossover trial of 36 patients with open-angle glaucoma, Korean red ginseng treatment significantly improved retinal peripapillary blood flow in the temporal peripapillary region (Kim et al. 2010). Blood pressure, heart rate, intraocular pressure and visual field indices did not change after placebo or red ginseng treatment. No significant changes were found in retinal peripapillary blood flow in either the rim region or the nasal peripapillary region. The results implied that red ginseng may be helpful in glaucoma management.

Wound Healing Activity

Application of ginseng ginsenoside Rd, a main ingredient of ginseng leaf, to an excision wound in mice showed an effective healing process (Kim et al. 2013f). Ginsenoside Rd significantly increased the proliferation and migration level of keratinocyte progenitor cells and human dermal fibroblasts in a dose-dependent manner and effectively induced collagen type 1 and down-regulated matrix metalloprotinase-1 (MMP-1) in a dose-dependent manner. All of these beneficial effects were associated with an induction of intracellular cAMP levels and phosphorylated cAMP response element-binding protein expression in the nucleus. The findings suggested that ginsenoside Rd can be used as a natural source for skin regeneration.

Hearing Loss Ameliorating Activity

Red ginseng and ginsenoside compound K promoted recovery from hearing threshold shifts caused by noise exposure resulting in noise-induced hearing loss in mice (Hong et al. 2011). Red ginseng, ginsenoside Rh_1 and ginsenoside compound K promoted recovery of central auditory function impairment, while red ginseng and ginsenoside compound K promoted recovery of hair cell functional damage in the cochlea. The results suggested that consumption of Korean red ginseng may facilitate recovery from noise-induced hearing loss. Administration of red ginseng ameliorated 3-nitropropionic acid (3-NP)-induced cochlear damage and 3-NP-induced hearing loss in BALB/c mice (Tian et al. 2013). Red ginseng treatment of C57BL/6 mice with inner ear disorder delayed age-related hearing loss and vestibular dysfunction (Tian et al. 2014). Vestibular dysfunction was observed in the tail-hanging and swimming tests, with significantly different severity scores and swimming times detected between the control and 150 mg/kg red ginseng-treated group at the age of 12 months. However, long-term and high-dose treatment with red ginseng may induce aggressive behaviour.

Antihypertrophic Activity

Ginseng root saponin (200 mg/kg, ×7 days, p.o.) attenuated the suppressive action of cortisone acetate (10 mg/kg, ×7 days, i.m.) on compensatory

adrenal hypertrophy in rats after unilateral adrenalectomy (Tanizawa et al. 1981). Ginseng saponin was also found to be antagonistic to the decrease of thymus weight and serum K^+ concentration induced by cortisone acetate in these rats. In histochemical studies, ginseng saponin showed no effect on the improvement of fatty metamorphosis induced by cortisone acetate in the liver of these rats.

Antidermatitis Activity

Korean red ginseng extract significantly reduced the total clinical severity score, ear thickness and the level of serum IgE in mouse with atopic dermatitis, whereas aprepitant reduced only the serum IgE level (Lee and Cho 2011). The extract not only decreased TNF-α, IFN-γ and substance P but also reduced the infiltration of FOXP3+ regulatory T (Treg) cells and CD1a+ Langerhans cells in the lesions, whereas aprepitant decreased only substance P and the infiltration of Treg cells. Ginseng ameliorated 2,4-dinitrochlorobenzene (DNCB)-induced dermatitis severity, serum levels of IgE and TARC (activation-regulated chemokine) and mRNA expression of TARC, TNF-α, IFN-γ, IL-4, IL-5 and IL-13 in mice (Choi et al. 2013). CG attenuated the Th1 and Th2 responses and leucocyte infiltration and reduced thickness of epidermis/dermis in ear lesions in NC/Nga mice. Ginseng inhibited TARC expression via blockade of NF-κB activation in HaCaT cells.

Oral administration of Korean red ginseng extract inhibited the development of atopic dermatitis-like skin lesions in trinitrochlorobenzene (TNCB)-treated NC/Nga mice by modifying thymic stromal lymphopoietin (TSLP), dendritic cells and, at least in part, the Th2 response (Cho and Cho 2013). Oral administration of 20-*O*-β-D-glucopyranosyl-20(*S*)-protopanaxadiol-fortified ginseng extract significantly attenuated *Dermatophagoides farinae* body extract-induced increases in atopic dermatitis score, ear thickness, scratching time and severity of skin lesions in NC/Nga mice (Kim et al. 2014a). Ginseng treatment also reduced the level of macrophage-derived chemokine in serum, infiltration of eosinophils and mast cells in skin and production of cytokines in splenocytes.

Antiemetic Activity

Pretreatment or post-treatment with Korean ginseng root extract significantly attenuated cisplatin-induced kaolin (pica) intake and markedly improved intake of normal food by rats (Raghavendran et al. 2011). Post-treatment with the lowest dose resulted in a significant anti-pica effect and improved food intake until 72 hours. The anti-pica effects of ginseng were further confirmed with haematological and histopathological findings. The findings indicated that ginseng improved the resistance of rats against emesis. They also reported that pretreatment with Korean ginseng protected rats against X-ray irradiation-induced acute pica to a moderate extent, leading to improved feeding behaviour (Raghavendran et al. 2012). The antiemetic effect of Korean ginseng was further confirmed on the basis of serotonin release and histopathological findings.

Renoprotective Activity

Ginseng extract exerted a stimulating effect on rat renal nuclear RNA synthesis resulting in an increased incorporation of labelled leucine into rat renal protein, and maximum activity was observed at 12 hours after the intraperitoneal administration (Nagasawa et al. 1977). Intraperitoneal administration of ginseng saponin preparation lowered the elevated adrenal cyclic AMP in a dose-dependent manner and increased plasma 11-hydroxycorticosteroid in intact rats (Hiai et al. 1979). In hypophysectomised rats, saponin treatment did not increase adrenal cyclic AMP, whereas corticotropin treatment did. It was concluded that ginseng saponin indirectly stimulated the adrenocortical function in intact rats.

The free radical scavenging activity of ginsenoside Re-alanine mixture was increased by heat processing (Lee et al. 2012b). Ginsenoside Re was gradually changed into Rg_2, Rg_6 and F_4 by

heat processing. The improved free radical scavenging activity by heat processing was mediated by the generation of antioxidant Maillard reaction products (MRPs). Antioxidant MRPs were generated from the reaction of glucose and alanine. Based on the viability results of LLC-PK1 renal epithelial cells, MRPs and less polar ginsenosides contributed to the combined renoprotective effect against oxidative renal damage. Maillard reaction was importantly involved in the increased antioxidant effect of ginsenoside by heat processing.

Kang et al. (2008) found that renal dysfunction of streptozotocin-induced diabetic rats was significantly ameliorated by ginseng 20(*S*)-ginsenoside Rg_3 administrations in a dose-dependent manner. The beneficial effects on diabetic renal damage were related to the inhibitory effect of 20(*S*)-Rg_3 against NMDA receptor-mediated nitrosative stress. Studies showed that ginsenosides from ginseng may be useful in enhancing the tolerance of the kidney against renal injury associated with cantharidin (Xu et al. 2013). Pretreatment of ginsenosides reduced the increases of serum creatinine, urine protein, urea nitrogen and histological change in rats caused by cantharidin. Ginsenoside pretreatment also reduced NRK cell apoptosis caused by cantharidin and augmented the cantharidin-lowered Bcl-2 expression. Korean red ginseng extract prevented renal impairment and pharmacokinetic changes by metformin in rats with renal failure induced by gentamicin (Lee et al. 2013g).

Haemolytic/Antihaemolytic Activity

Some fractions of ginseng were haemolytic and some fractions were antihaemolytic, exhibiting protective activity against saponaria saponin haemolysis and lecithin haemolysis (Namba et al. 1973). By treatment with acid hydrolysis, haemolytic fractions afforded panaxatriol, and protective fractions gave panaxadiol. Saponins with genuine sapogenins 20-*S*-protopanaxatriol were found to be haemolytic and saponins with genuine sapogenins 20-*S*-protopanaxadiol were antihaemolytic. Among the seven ginseng saponins, Rd, Re and Rb_2 showed more potent haemolytic actions than those of the rest, and the potencies were proportional to their toxicities (Kaku et al. 1975). Ginseng ginsenosides inhibited 2,2′-azobis(2-amidinopropane hydrochloride) (AAPH)-induced haemolysis of the erythrocyte in the order of 50 % inhibitory concentration IC_{50} values $Rb_3 \sim Rb_1 \ll Rg_2 < Re < Rg_1 \sim Rc < Rh_1 < R_1$. Rb_1, Rc and Rg_2, as antioxidants, prolonged the lag time of haemolysis (Liu et al. 2002). Contrariwise, Rg_3, Rd and Rh_1, together with high concentration of Rb_3, Rg_1 and Rh_2, function as pro-oxidants to accelerate AAPH-induced haemolysis. The order of synergistic antioxidative properties with α-tocopherol was $Rb_1 > Rc > Re > Rh_1 > R_1 > Rg_2 > Rb_3$. Rg_3, Rd and Rh_2, however, act as synergistic pro-oxidants in the above experimental system. Rg_1 did not show any synergistic antioxidative property. In in-vitro studies it was found that the following ginseng ginsenosides protected human erythrocytes against hemin-induced haemolysis, and the overall sequence was $Rc > Rd > Re \sim Rb_1 > Rg_1 \sim Rh1 > Rb_3 \sim Rg2 \sim R_1 \sim$ pseudoginsenoside $F_{11} \sim$ 20(*S*)-protopanaxatriol (PT) (Li and Liu 2008). Ginsenosides Rh_2 and Rg_3 intensified haemolysis in the presence of hemin and initiated haemolysis even in the absence of hemin. Further 20(*S*)-protopanaxadiol (PD) promoted haemolysis appreciably, whereas PT protected erythrocytes efficiently.

Intestinal Transit Activity

Ginseng root improved both carbachol-induced and $BaCl_2$-induced hyperperistalsis of the small intestine in mice suggesting that both an inhibitory effect on the cholinergic nervous system and direct suppressive effect on muscles were involved in the ameliorative effect of ginseng root on the accelerated small intestinal transit (Hashimoto et al. 2003). Ginsenoside Rb_1 and ginsenoside Rd, the major components of ginseng roots, also improved accelerated small intestine transit.

Metabolic Stimulating Activity

Ginseng extract stimulated RNA polymerase activity in rat liver nuclei (Hiai et al. 1971). The increase in the activity of the polymerase due to ginseng extract did not disappear even when the synthesis of bulk nuclear protein was greatly inhibited by puromycin.

Ginseng root extract increased the incorporation rate of labelled precursors into liver nuclear RNA at 4 hours and into cytoplasmic polysomal RNA at 5.5–6.0 hours after a single-dose intraperitoneal injection in rat (Oura et al. 1971). Intraperitoneal administration of ginseng extract (fraction 3 or 4) to rat was found to increase the rate of synthesis of serum proteins such as albumin and γ-globulin (Oura et al. 1972a). The incorporation rate of ^{3}H-leucine into serum proteins was significantly increased 4 hours after the injection of fraction 3. The increased rate of protein synthesis reached a maximum of about 8–12 hours after the administration, and 46–49 % increase in the rate of serum protein synthesis was observed. A single intraperitoneal injection of ginseng root extract (fraction 4) increased the incorporation rate of labelled precursor into cytoplasmic polysomal ribonucleic acid (RNA) of the rat liver (Oura et al. 1972b). The content of heavy polysomes (over hexamer) in postmitochondrial supernatant from liver treated with fraction 4 was observed to increase at 6 and 10 hours after treatment. Particularly, 29S ribosomal and 9-10S messenger RNAs were stimulated significantly.

In an amino acid incorporation system in-vitro, stimulatory activities of microsomes and polysomes from ginseng-treated rat liver were more active by 85 and 67 % than those from normal liver, respectively. Ginseng saponin mixture (fraction 5) exhibited high activity for such incorporation of labelled leucine into serum protein at 6 hours after a single intraperitoneal injection in a mouse (Oura et al. 1975). Administration of ginseng root ginsenosides Rb_1 and Rc to rats stimulated biosynthesis of rat serum protein (Shibata et al. 1976). Intraperitoneal injection of ginsenoside Rb_1 increased while Rc decreased the incorporation of ^{3}H-orotic acid into nuclear RNA of rat liver, and Rg_1 did not affect it (Iijima et al. 1976). Furthermore, intraperitoneal administration of Rb_1 enhanced and Rc repressed RNA polymerase activity. Both purified ginsenosides did not show any effect on RNA polymerase activity when added in-vitro. Apoproteins of chylomicrons and very low-density lipoprotein were stimulated. Fraction 4 of ginseng root stimulated DNA and protein syntheses in rat testes (Yamamoto et al. 1977a). Oral administration to rats of fraction 3 from ginseng root and addition of fraction 4 in-vitro stimulated DNA, protein and lipid synthesis in bone marrow cells (Yamamoto et al. 1977b). The numbers of mitosis were increased by oral administration of fraction 3. The numbers of total nucleated cells in bone marrow and reticulocytes in peripheral blood were significantly increased. Administration of seven ginseng saponins isolated (ginsenosides Rb_2, Rc, Rc_2, Rd, Re and Rg_1), except for ginsenoside Rb_1, caused an increase of leucine incorporation over that in control mice. Ginseng aqueous extracts inhibited intracellular protein degradation in confluent cultures of IMR-90 human diploid fibroblasts and stimulated protein synthesis in human fibroblasts indicating that components of ginseng extract are capable of acting directly on human cells to promote protein accumulation (Lu and Dice 1985).

Results of in-vivo studies suggested that ginseng saponin decreased the glycogen stores, but the degree of its effect was regulated by the nutritional status of rats (Yokozawa et al. 1976). Administration of the ginseng root extract (fraction 5) increased the activity of hepatic pyruvate kinase in rats fed on a laboratory pellet chow (Yokozawa et al. 1979). However, rise of the enzyme activity due to ginseng treatment did not seem to involve de novo protein synthesis which required mRNA production. In contrast, when the diet contained an excess of carbohydrate, ginseng treatment resulted in a decreased enzyme level, and the elimination of food resulted in the loss of the effect of ginseng principle. Treatment of rats with saponin (fraction 5) from ginseng roots caused a decrease in the activity of hepatic serine dehydratase (Yokozawa and Oura 1979). Maximum decrease in the enzyme activity was observed 2 hours after the administration of the

ginseng saponin. In contrast, when the animals were starved, ginseng treatment resulted in an increased level of the enzyme.

Administration of ginsenoside Rb_2 to streptozotocin-induced diabetic rats resulted in increases of total protein and lysine, glycine, glutamine, arginine, etc. in serum, while no significant change of serum albumin was observed (Yokozawa et al. 1987a). In the liver, the urea content was decreased with a concomitant increase of ribonucleic acid content. The increase in ribosomes caused by the administration of ginsenoside Rb_2 was mainly due to the increase in membrane-bound ribosomes. Ginsenoside Rb_2 exhibited a normalising action on the hepatic concentrations of glutamine, thymine, phenylalanine and tyrosine. Daily intraperitoneal administration of ginsenoside Rb_2 for 3 or 6 days to streptozotocin-induced diabetic rats resulted in an increase of RNA polymerase I activity, as well as an increment of RNA polymerase II activity (Yokozawa et al. 1993). The results suggested that ginsenoside Rb_2 may promote the synthesis of rRNA and mRNA.

Gommori et al. (1976) observed an enhancement of cholesterol synthesis in liver slices incubated with ^{14}C-acetate taken from rats treated with ginsenosides Rb_1, Rc and Rd thus confirming the in-vivo incorporation of ^{14}C-acetate into liver and serum cholesterol. However the ginsenosides did not exhibit any effect on cholesterol synthesis by normal liver slices when added to the incubation mixture. Earlier Sakakibara et al. (1975) reported the enhancement of cholesterol biosynthesis from incorporation of ^{14}C-acetate into serum and liver cholesterol by administered saponins ginsenosides Rb_1, Rc, Rd, Re and Rg_1, especially by ginsenoside RB_1.

A single intraperitoneal administration of ginseng root extract (fraction 4) increased the incorporation of labelled precursor into total lipid of liver and epididymal adipose tissue in rats (Yokozawa et al. 1975). In contrast, the concentration of serum triglycerides was slightly decreased after treatment with fraction 4. Further, reduction of blood sugar level and liver glycogen content by ginseng extract administration was observed. In further studies, incorporation of 14C-acetate into total lipid and the glycogen content in the liver were determined 4 hours after the intraperitoneal administration of ginseng extract (fraction 4) to rats (Yokozawa and Oura 1976). Treatment of rats with ginseng ginsenoside Rb_2 stimulated lipid and sugar metabolism (Yokozawa et al. 1984a). Hepatic glycogen content decreased 8 hours after the treatment but recovered 24 hours after treatment. There was also a dramatic increase in the phosphofructokinase activity, peaking at 12 hours. Accumulation of lipid in adipose tissue was observed 10–12 hours after the administration, but no significant changes in the total lipid, triglyceride, total cholesterol, phospholipid, glucose, pyruvate and lactate levels of the liver were observed throughout the experimental period. A transitory increase of hepatic glucose-6-phosphate dehydrogenase activity was observed 2–4 hours after the treatment. A stimulation of glucose-6-phosphate dehydrogenase activity beginning 4 hours was observed after the administration of ginsenoside Rb_2 (Yokozawa et al. 1984b). At this time, a slight increase of acetyl-coenzyme A carboxylase activity was observed, and a significant increase was noted 16 hours after the treatment. The maximum increase in malic enzyme activity was observed at 12 hours. An increase in the lipolytic activity of lipoprotein lipase was observed 4 hours after the intraperitoneal administration of ginsenoside Rb_2, reaching a maximum (262 %) at 16 hours after the treatment, while a repressive effect was observed on hormone-sensitive lipase activity throughout the experimental period. Administration of ginsenoside Rb2 to rats also increased the triglyceride content in adipose tissue. The results suggested that ginsenoside Rb2 brought about the accumulation of triglyceride in adipose tissue as a result of its stimulating action on the lipogenic pathway.

Anti-ageing Activity

The results of studies by Lee et al. (2007b) suggested that ginseng root extract promoted collagen production in human dermal fibroblast cells. Additionally, the extract was found to induce the phosphorylation of Smad2, an important

transcription factor in the production of type I procollagen. When applied topically in a human skin primary irritation test, ginseng extract did not induce any adverse reactions and thus may be considered as an attractive, wrinkle-reducing candidate for topical application.

Topical application of total ginseng saponins (10 pg or 100 ng/mouse) and ginsenoside Rb_1 (100 fg, 10 pg, or 1 ng/mouse) significantly inhibited increases in skin thickness and wrinkle formation and the reduction in skin elasticity induced by long-term UVB irradiation (Kim et al. 2009c). Topical application of total saponins and ginsenoside Rb1 prevented increases in apoptotic, Ki-67- and 8-hydroxy-2′-deoxyguanosine-positive cells induced by UVB exposure. Further, total saponins and ginsenoside Rb_1 prevented the disruption of collagen fibres induced by the long-term UVB irradiation. Ginsenoside Rb_1 (100 fg, 10 pg and 1 ng/ml) increased the Bcl-2 expression level in UVB-treated human keratinocytes. The protective effect of ginsenoside Rb_1 on UVB-mediated apoptosis may be due to the upregulation of Bcl-2 expression. The results suggested that the protective effect of ginsenoside Rb_1 on skin photoageing induced by chronic UVB exposure may be due to the increase in collagen synthesis and/or the inhibition of matrix metalloproteinase expression in dermal fibroblasts.

Animal studies showed that fermented *Panax ginseng* extract (GINST) had antioxidant and anti-ageing properties (Ramesh et al. 2012b). Treatment with GINST could improve the antioxidant status during ageing, thereby minimising the oxidative stress and occurrence of age-related disorders associated with free radicals. Increased levels of aspartate aminotransferase (AST), alanine aminotransferase (ALT), urea and creatinine were observed in the serum of aged rats. Increased levels of malondialdehyde (MDA) and significantly lowered activities of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR) and glutathione-S-transferase (GST) were observed in the liver, kidneys, heart and lungs of aged rats, when compared with those in young rats. Quantitative analysis of the nonenzymatic antioxidants such as reduced glutathione (GSH), ascorbic acid and α-tocopherol levels showed significantly lower values in the liver, kidneys, heart and lungs of aged rats. In contrast, administration of GINST to aged rats resulted in increased activities of SOD, CAT, GPx, GR and GST, as well as elevation in GSH, ascorbic acid and α-tocopherol levels. Besides, the level of MDA, AST, ALT, urea and creatinine were reduced on the administration of GINST to aged rats.

Anti-infertility/Aphrodisiac Activity

Studies by Kim et al. (1976) found that ginseng facilitates mating behaviour of male albino rats. Under the influence of ginseng, male rats (a) began ejaculation earlier and repeated the action more often in a 45-minutes observation period and (b) deposited more copulation plugs in 10 days. Rats that received 5 % ginseng for 60 days experienced a significant increase in blood testosterone level (Fahim et al. 1982). Prostate weight in the treated animals was significantly reduced as compared to the control animals. There was an increase in daily food consumption without an increase in body weight of treated animals. Pak et al. (2005) found that administration of Korean red ginseng total saponins to mature female Sprague-Dawley rats with oestradiol valerate-induced polycystic ovary attenuated the elevated expression of nerve growth factor (NGF) in the ovaries. Korean red ginseng extract was found to have a relaxing effect on rabbit vaginal smooth muscle tissue and to have potential as a therapeutic agent for female sexual dysfunction (Kim et al. 2008b). The relaxation effects might be mediated partly through the NO pathway and hyperpolarisation via Ca^{2+}-activated K^+ channels.

Studies by Choi et al. (1999) confirmed that long-term administration (3 months) of Korean red ginseng in rabbits and rats enhanced penile erectile capacity both in in-vitro and in-vivo experiments. Its action was found to be mediated by endothelium-derived relaxing factor and peripheral neurophysiologic enhancement. Earlier in-vitro studies found that Korean red ginseng extract had a relaxing effect on the rabbit corpus cavernosal tissue in a dose-dependent manner

(Choi et al. 1998). The relaxation action of EKG red ginseng was mediated by multiple action mechanisms that included increasing the release of NO from the corporal sinusoids, increasing intracellular calcium sequestration and a hyperpolarising action. Studies in streptozotocin-induced, non-insulin-dependent diabetes mellitus (NIDDM) rats found that oxidative stress to cavernous tissue may be a contributory factor in erectile dysfunction in diabetics (Ryu et al. 2005). Treatment with Korean red ginseng preserves potency in the NIDDM rats through its antioxidant activity. Both glutathione and malondialdehyde levels in diabetic rats treated with red ginseng were comparable to their age-matched controls while there were significantly reduced in untreated diabetic rats.

Korean ginseng berry extract GB0710 was found to have a greater relaxation effect on rabbit penile corpus cavernosum smooth muscle than did Korean red ginseng root extract (Cho et al. 2013b). GB0710 increased intracavernosal pressure in a rat in-vivo model in both a dose- and duration-dependent manner. This relaxation effect appeared to be mediated by NO production.

Ginseng-treated rats exhibited significantly increased sperm count and motility with enhanced levels of cAMP-responsive element modulator messenger RNA and protein, suggesting that ginseng appeared to induce spermatogenesis via cAMP-responsive element modulator activation in rat testes (Park et al. 2007b).

The study of Lee et al. (2007a) demonstrated that 2,3,7,8-tetrachlorodibenzo-*p*-dioxinthe induced the pathological damage such as reduced seminiferous tubular diameter, an increased number of damaged tubules (maturation arrest, eosinophilic degeneration and spermatid giant cells) and genotoxical (DNA damage and elevated expression of CYP1A1 mRNA) damage in rat testes, while *P. ginseng* extract treatment exhibited a therapeutic capacity to reduce these effects via reduction of CYP1A1 mRNA. *Panax ginseng* root aqueous extract showed cytoprotective effect on gallic acid-induced toxicity in TM3 mouse Leydig cells by decreasing the intracellular production of hydrogen peroxide (Park et al. 2007a).

In a double-blind, placebo-controlled, crossover study of 45 patients with clinically diagnosed erectile dysfunction, administration of ginseng 90 mmg/day for a duration of 8 weeks on treatment and 2 weeks of washout was found to be effective in treating erectile dysfunction (Hong et al. 2002). The mean International Index of Erectile Function scores were significantly higher in patients treated with Korean red ginseng than in those who received placebo. Scores on questions 3 (penetration) and 4 (maintenance) were significantly higher in the ginseng than in the placebo group. Among other variables penile tip rigidity on RigiScan showed significant improvement for ginseng versus placebo. In a 12-week placebo-controlled study of 35 patients with erectile dysfunction (23 patients ginseng treated, 12 placebo), the International Index of Erectile Function (IIEF-5) score improved significantly in patients treated with mountain ginseng, suggesting that mountain ginseng extract could be a treatment candidate for erectile dysfunction (Kim et al. 2006).

Antiosteoarthritic/Osteogenic Activity

Panax ginseng and its ginsenosides Rd and Rb_3 suppressed matrix metalloproteinase MMP3 secretion in S12 murine articular cartilage cell, and ginsenosides Rd and Rb_3 were the major elements involved in the suppression of MMP3 by ginseng (Shin et al. 2009). Further, the suppression of MMP3 by ginseng occurred via the inhibition of phospho-p38 activation. The results indicated that ginseng may exert a protective effect against the cartilage degradation of osteoarthritis.

Ginsenoside Rg_1 promoted the proliferation and odontogenic/osteogenic differentiation of human dental pulp stem cells through alteration of gene expression profiles (Wang et al. 2014b). Gene expressions of dentin sialophosphoprotein (DSPP), alkaline phosphatase (ALP), osteocalcin (OCN), bone morphogenetic protein-2 (BMP-2), fibroblast growth factor 2 (FGF2) and protein expressions of BMP-2 and FGF2 were increased

compared with the untreated group. Several ginsenosides Rc, Rd, Rf, Rg_3 and F4 were found to inhibit matrix metalloproteinase MMP-13 expression in IL-1β-treated human chondrocytes (Lee et al. 2014g). Ginsenosides F4 and Rg_3 blocked cartilage breakdown in rabbit cartilage tissue culture. Thus, it was suggested that certain ginsenosides may have therapeutic potential for preventing cartilage collagen matrix breakdown in diseased tissues such as those found in patients with arthritic disorders.

Hair Stimulating Activity

Ginseng fruit extract significantly increased the proliferation of human hair dermal papilla cells hair regeneration in C57BL6 mice in dose- and time-dependent manners through antiapoptotic activation (Park et al. 2011b). Topical administration of ginseng fruit extract might have hair regeneration activity for the treatment of hair loss.

Antitrypanosomal Activity

Hexane extracts of *Panax ginseng*, *Panax notoginseng* and the pure panaxynol were cytotoxic to and human cancer cell line HeLa to *Trypanosoma brucei brucei* and at the same time highly selective against *Trypanosoma brucei brucei*, whereas methanol extracts and 12 isolated ginsenosides were significantly less toxic and showed only weak selectivity (Herrmann et al. 2013). Panaxynol was cytotoxic against *Trypanosoma brucei brucei* at the concentration of 0.01 μg/mL with a selectivity index of 858, superior even to established antitrypanosomal drugs. The high selectivity together with a cytotoxic concentration in the range of the bioavailability suggested panaxynol and other polyacetylenes in general to be very promising lead compounds for the treatment of African trypanosomiasis.

Hematopoietic Activity

Studies by Chen et al. (2009) suggested that total saponins of *Panax ginseng* may enhance the erythroid differentiation of human $CD34^+$ hematopoietic stem and progenitor cells via Epo/EpoR-mediated $JAK_2/STAT_5$ signalling pathway.

Anti-lipolytic Activity

A metal binding tetradecapeptide, isolated from ginseng root, displayed anti-lipolytic activity in an isolated rat fat cell assay (Kajiwara et al. 1996). The results suggested that the tetradecapeptide may perform its anti-lipolytic activities through an ability to modulate the level of free cellular Mg^{2+} and Mn^{2+} ions.

Drug Potentiating Activity

Co-administration of ginseng ginsenosides Rg_1, Rb_1 and schisandrin markedly increased the systemic exposure level of each compound in-vivo (Zhan et al. 2014). The mixture of ginsenosides Rg_1, Rb_1 and schisandrin administration exhibited synergistic effect of inducing NO release in isoproterenol (ISO)-induced myocardial ischaemia rats, while administration of the individual compounds had no effect of inducing real-time NO release. Ginsenoside Rb_1 and/or schisandrin in mixture could significantly postpone the elimination of ginsenoside Rg_1 in rat serum.

Anticataract Activity

Intraperitoneal injection of sun ginseng extract and non-saponin fraction to rats with cataract induced by sodium selenite had significantly lower incidence and smaller mean cataract area compared with the saponin fraction (Lee et al. 2010b).

Steroid Hormone Modulating Activity

Ginseng ginsenosides Rb1, Rb2, Rc, Rd, Re and Rg1 (GRb1, GRb2, etc.) and their 20S- and 20R-prosapogenins (S-PS and R-PS), 20S- and 20R-protopanaxadiols (S-PPD and R-PPD) and a mixture of 20S- and 20R-panaxadiols (SR-PD) at various doses administered to rats intraperitoneally affected plasma corticosterone secretion activity (Hiai et al. 1983). Most of these 11 compounds did not significantly affect the plasma glucose level at 30 minutes after treatment. Eight potential biomarkers were found and identified in the urinary excretion of diabetic rats treated with water-soluble ginseng polysaccharide (WGP) (Niu et al. 2012). Significantly increased inosine, serotonin, phenylpropionylglycine and dodecanedioic acid showed the effect of WGP on purine metabolism, tryptophan metabolism, fatty acid metabolism and energy metabolism. 1-Methyladenine, 4-deoxyerythronic acid, 5-hydroxyhexanoic acid and tetrahydrocortisol were significantly decreased which indicated that WGP could regulate DNA metabolism, organic acids metabolism and steroid hormone metabolism. An end metabolite of the protopanaxatriol saponins in ginseng, 20(s)-protopanaxatriol (M4), strongly reduced adrenal corticotropic hormone -stimulated cortisol production in the adrenal fasciculata cells in-vivo (Hasegawa et al. 2013). Additionally, M4 significantly inhibited the production of pregnenolone, progesterone, deoxycorticosterone, cortisol and corticosterone in a dose-dependent manner. The results also suggested that M4 inhibited the conversion from cholesterol to pregnenolone because the production of pregnenolone was reduced.

Pharmacokinetics and Metabolism Activities

Ginseng ginsenoside Rg_1 was absorbed rapidly from the upper parts of the digestive tract, accounting for 1.9–20.0 % of the dose of Rg_1 administered orally to rats (Odani et al. 1983a). However, ginsenoside Rg_1 was not found in the brain. Ginsenoside Rg_1 was excreted into rat urine and bile in a 2:5 ratio. It was also proved that ginsenoside Rg_1 was not significantly metabolised in the liver. However, the decomposition and/or metabolism of ginsenoside Rg_1 in rat stomach and large intestine were confirmed. Little ginsenoside Rb_1 was absorbed from the digestive tract after oral administration (100 mg/kg) to rats (Odani et al. 1983b). The serum level of Rb1 in rats after intravenous injection (5 mg/kg) declined biexponentially, and the half-life of the β-phase was 14.5 hours. Rb_1 was gradually excreted into urine, but not bile. Unabsorbed Rb1 in the digestive tract was rapidly decomposed and/or metabolised mainly in the large intestine. These results were quite different from our results on ginsenoside Rg_1 in rats.

Five decomposition products of ginsenoside Rb_2 were found in the rat large intestine after oral administration (Karikura et al. 1990). They were identified as ginsenoside Rd; 3-*O*-β-D-glucopyranosyl-20-*O*-[α-L-arabinopyranosyl(1→6)-β-D-glucopyranosyl]-20(*S*)-protopanaxadiol; ginsenoside F_2; 20-*O*-[α-L-arabinopyranosyl(1→6)-β-D-glucopyranosyl]-20(*S*)-protopanaxadiol; and compound K. After ingestion, ginsenoside Rb_2 was a little decomposed in the rat stomach, and a small quantity of an unidentified metabolite, which was different from the hydrolysed products (20(*R*, *S*)-ginsenoside Rg_3) in 0.1 N HCl, was observed (Karikura et al. 1991a). The metabolite was separated into four compounds, which were determined to be 25-hydroxy-23-ene; 24-hydroxy-25-ene; 25-hydroperoxy-23-ene; and 24-hydroperoxy-25-ene derivative of Rb_2, respectively. As in the case of Rb_2 reported previously, Rb_1 was hydrolysed to 20(*R*, *S*)-ginsenoside Rg_3 in 0.1 N HCl (Karikura et al. 1991b). In contrast, hydroperoxidation of Rb_1 occurred in rat stomach; the major hydroperoxide was separated and identified as the 25-hydroperoxy-23-ene derivative of Rb_1. In rat large intestine, five decomposition products of Rb1 were detected and identified as gypenoside XVII, ginsenoside Rd, ginsenoside F2, compound K and 25-hydroperoxy-23-ene derivative of Rb_1. Tetracycline-resistant bacteria

decomposed both Rb_1 and Rb_2 to their respective prosapogenins, except for Rd, and their respective hydroperoxides, while Rd and hydroperoxides of Rb_1 and Rb_2 were produced by enteric enzymes.

Administration of ginseng in the rat resulted in a reduction of bile flow and bile secretion of total lipids and cholesterol, while it increased the secretion of proteins in a dose-dependent manner (Abdul Salam et al. 2002). After oral dosing, ginsenoside Rh_2 was found to be distributed mainly to the liver and gastrointestinal tissues in rats (Gu et al. 2009). Systemic clearance of Rh_2, however, was low – around 2 and 20 ml/minute/kg in dogs and rats, respectively. Only 1 % of dosed Rh_2 was recovered in excreta of rats as the intact form after oral administration. Low membrane permeability, efflux transport, pre-systemic elimination (degradation in acidic condition; metabolism in intestine tissue and contents), as well as low solubility largely accounted for the low bioavailability of Rh_2. They found that micronisation of the dose almost doubled the rate of absorption in dogs. Eleven and nine metabolites together with ginsenoside Re were detected and identified in rat urine collected after intravenous and oral administration of ginsenoside Re, respectively (Yang et al. 2009). Metabolites of ginsenoside Re were characterised as three oxidation, two combinative and six deglycosylated metabolites. Ginsenoside Re was rapidly cleared from the body with a short half-life, and oral absorption of ginsenoside Re was poor after intravenous and oral administration of pure Re or ginseng berry extract in mouse (Joo et al. 2010). Ginseng berry extract elicited greater absorption at equivalent dosage administered, indicating that it might be a good form for ginsenoside Re intake.

When ginsenosides Rb_1 and Rb_2 were anaerobically incubated with human intestinal microflora, these ginsenosides were metabolised to 20-*O*-β-D-glucopyranosyl-20(*S*)-protopanaxadiol (compound K) and 20(*S*)-protopanaxadiol (Bae et al. 2000). *Eubacterium* sp., *Streptococcus* sp. and *Bifidobacterium* sp., which more potently hydrolysed gentiobiose than sophorose, metabolised ginsenoside Rb_1 to compound K via ginsenoside Rd rather than gypenoside XVII. However, *Fusobacterium* K-60, which more potently hydrolysed sophorose than gentiobiose, metabolised to compound K via gypenoside XVII. Ginsenoside Rb_2 was also metabolised to compound K via ginsenoside Rd or compound O by human intestinal microflora. *Eubacterium* sp., *Streptococcus* sp. and *Bifidobacterium* sp. metabolised ginsenoside Rb_2 to compound K via ginsenoside Rd rather than compound O. *Fusobacterium* K-60 metabolised ginsenoside Rb_2 to compound K via compound O. *Bacteroides* sp., *Eubacterium* sp. and *Bifidobacterium* sp. metabolised ginsenoside Rg_3 to protopanaxadiol via ginsenoside Rh_2 (Bae et al. 2002b). However, *Fusobacterium* sp. metabolised ginsenoside Rg_3 to ginsenoside Rh_2 alone. 20(*S*)-Ginsenoside Rg_3 was quickly transformed to 20(S)-ginsenoside Rh_2 or 20(*S*)-protopanaxadiol in an amount 19-fold compared with the transformation of 20(*R*)-ginsenoside Rg_3 to 20(*R*)-ginsenoside Rh2 or 20(*R*)-protopanaxadiol. When ginsenoside Rc was anaerobically incubated with human faecal microflora, all specimens metabolised ginsenoside Rc to the main metabolite compound K and protopanaxadiol (Bae et al. 2002a). *Bacteroides* sp., *Eubacterium* sp. and *Bifidobacterium* sp. potently transformed ginsenoside Rc to compound K. *Bifidobacterium* K-103 and *Eubacterium* A-44 transformed Rc to compound K via ginsenoside Rd, and *Bacteroides* HJ-15 and *Bifidobacterium* K-506 metabolised it to compound K via ginsenoside Mb, which was isolated as a new metabolite.

Transformed ginsenoside Rg_3 and delta20-ginsenoside Rg3 from acid-treated ginseng extract were metabolised to ginsenoside Rh_2 and delta20-ginsenoside Rh_2, respectively, by human faecal microflora (Bae et al. 2004). *Bacteroides* sp., *Bifidobacterium* sp. and *Fusobacterium* sp. potently transformed ginsenoside Rg_3 to ginsenoside Rh_2.

Toxicity Studies

Ginseng saponins showed weak toxicities in mice; especially, Rg1, Rf and Rb 1, which contained glucose as a sugar component, were

weaker in their toxicities than the rest, which contained arabinose and/or rhamnose (Kaku et al. 1975). It was also noted that the saponins containing protopanaxadiol as sapogenin were more toxic than those containing protopanaxatriol. There was neither abnormality nor mortality of the experimented mice found in the acute and cumulative toxicity tests (Ding et al. 1993). The Ames mutation test on *Salmonella typhimurium* test strains TA97, TA98, TAl00 and TA102 was negative. The results of teratogenesis test showed that the ginseng cell cultures did not cause teratogenesis in both testis and chromosome of marrow cell in mice. The highest dose of cell cultures of *P. ginseng* was 2.5 g/kg. Two percent starch was taken as negative contrast and 50 mg/kg cyclophosphamide as positive contrast.

Ginsenoside Re, active ingredient of ginseng, was well tolerated up to a 375 mg/kg/day oral dosage level and nontoxic in both male and female rats. It did not induce death, adverse effects or dose-dependent changes in feed consumption or body weight gain (Lu et al. 2012). No abnormality of any organs was noted in both gross and histopathological examinations.

Drug Antagonistic Activity

In a randomised, open-label, controlled study of 25 ischaemic stroke patients, co-administration of *P. ginseng* and warfarin did not influence the pharmacologic action of warfarin (Lee et al. 2008b). In contrast, in a 4-week, randomised, double-blind, placebo-controlled trial of 20 healthy patients, administration of American ginseng reduced warfarin's anticoagulant effect. In a recent paper, Shao and Jia (2013) reported possible serious interactions between nutraceutical ginseng and warfarin in patients with ischaemic stroke.

Other Adverse Issues

The oral administration of *Panax ginseng* as powder caused leucocytosis in rabbits' action (Yamada 1955). In 1979, the term ginseng abuse syndrome was coined as a result of a study of 133 people who took ginseng for 1 month (Siegel 1979). Most subjects experienced central nervous system stimulation. At a dose of <15 g/day, subjects experienced depersonalisation and confusion. At a dose of >15 g/day, some subjects experienced depression. Fourteen patients experienced ginseng abuse syndrome, characterised by symptoms of hypertension, nervousness, sleeplessness, skin eruption and morning diarrhoea. Vaginal bleeding has been reported in cases of ginseng use (Greenspan 1983). Punnonen and Lukola (1980) reported oestrogen-like effect of ginseng on the vaginal epithelium and competition by saponins with 17β-oestradiol and R5020 for binding to human myometrial receptor proteins. Hopkins et al. (1988) reported a case of postmenopausal bleeding attributed to the use of topical ginseng face dream. Ginseng appeared to have an oestrogen-like effect on genital tissues.

Jones and Runikis (1987) reported a case of interaction between Asian ginseng and the antidepressant medication phenelzine when taken concurrently, resulting in symptoms like insomnia, headache, irritability and visual hallucinations. An episode of Stevens–Johnson syndrome was reported in a 27-year-old man following ingestion of ginseng at a dose of two pills for 3 days; the patient recovered after 30 days (Dega et al. 1996).

The neuro-excitatory β-ODAP (β-*N*-oxalyl-L-α,β-diaminopropionic acid), suggested to be the cause of the crippling neurolathyrism, was the major component in ginseng seed extract (70 % of the total free amino acids detected) and showed the highest concentration (0.43 % by wt) compared to that in the different parts of young (1–3-year-old) ginseng plants (Kuo et al. 2003). β-ODAP concentration was higher in the shoots as compared to the roots and declined in older plants. Another neuroactive nonprotein amino acid, GABA (γ-aminobutyric acid), increased dramatically after germination and reached highest concentration in different parts of 3-year-old plants. Liao et al. reported a case of an 83-year-old woman with chronic kidney disease who developed atrial fibrillation with slow ventricular response possibly related to ginseng (Liao et al. 2010).

The authors reasoned the bradyarrhythmia due to digitalis glycoside-like effects of ginseng in the condition of renal failure that had not been reported before.

A case of manic episode with psychotic symptoms without previous psychiatric background after consumption of Korean ginseng was reported by Vera-Barrios et al. (2013). Two cases of new-onset manic psychoses associated with high-dose, chronic ginseng use was reported by Norelli and Xu (2014). A 23-year-old man developed acute mania after 1 month of daily ginseng use and intermittent cannabis use. A 79-year-old man developed hypomania while using ginseng and yohimbine for erectile dysfunction and had a recurrence of mania after stopping yohimbine but increasing his daily intake of ginseng. Symptoms of mania fully remitted within days upon discontinuation of ginseng and supportive treatment.

Studies by Poindexter et al. (2006) found that fully developed rat cardiomyocytes were able to accommodate higher doses of ginseng than neonatal cells and that the effects of ginseng on newly formed, developing myocytes could be extremely deleterious to the fetus. However, for adults, ginseng might well be a "tonic" in its ability to increase beating and intramyocytic calcium levels. Cardiotonic effects in adult cells (cardiotoxicity in neonatal cells) were most profound with Asian ginseng (2.6 times that of Siberian ginseng, 1.6 times that of Indian ginseng) probably due to the active ingredients (ginsenosides in Asian, eleutherosides in Siberian and withanolides in Indian) being structurally different.

Traditional Medicinal Uses

Panax ginseng has been used in China, Korea Tibet and Indochina for thousands of years as a traditional medicine. Therapeutic properties of ginseng have been known by Chinese popular medicine since time immemorial. Ginseng has been used under various preparations such as teas, tinctures, wines, pill and unguents for the prevention of ageing, tiredness, headaches, amnesia, tuberculosis, diabetes, illness of the liver, heart, kidneys, nervous system, etc. (Popov and Goldwag 1973). It is said in Chinese medicine that Ginseng root has an antifatigue, antihypothermia, antidiabetic and sedative activities (Takagi et al. 1972b). It has been also utilised to develop physiological strength and to increases spontaneous movement of digestive system.

Ginseng has been used for several thousand years in the Orient as a tonic, prophylactic and "restorative" agent (Bahrke and Morgan 1994). In traditional Chinese medicine (TCM), ginseng is a highly valued herb and has been applied to a variety of pathological conditions and illnesses such as hypodynamia, anorexia, shortness of breath, palpitation, insomnia, impotence, haemorrhage, diabetes, cancer prevention and ageing process (Xiang et al. 2008; Ruan et al. 2010). *Panax ginseng* has been used in TCM to enhance stamina and capacity to deal with fatigue and physical stress (Li and Liu 2008). Ginseng radix (ginseng root) is prescribed in many Chinese medicines as a stomachic and for the purpose of antidiarrhoic effect, metabolic promotion and hematic effects and has been well known as one of the representative drugs of nutritious tonics (Otsuka et al. 1981). In TCM, ginseng is regarded as warm, sweet and slightly bitter, tones up energy, produces fluid, calms the nerves and affects the spleen and lungs (Lu 2005). Ginseng is prescribed for poor appetites, fatigue, upset stomach, diarrhoea, coughs, excessive perspiration, forgetfulness, impotence, frequent urination, diabetes, excessive menstruation, nervous disorders, shortness of breath, tonic for general weakness and anaemia (Lu 2005; Wee and Keng 1990). Korean ginseng tea (KGT), prepared from the roots of *Panax ginseng*, is widely used by Korean people for antistress, antifatigue and endurance-promoting effects (Shah et al. 2005). *P. ginseng* is traditionally used as a remedy for cancer, inflammation, stress and ageing (Kim et al. 2013b). In Korea ginseng is regarded as antioxidant, antifatigue, immunostimulant and hypoglycaemic, increases HDL cholesterol, stimulates ADH enzyme and is used for weakness, diabetes, alcoholism and endometritis (NPRI 1998). The medical effects described in the related reference books categorise

ginseng as a "mild" medication, a tonic that strengthens and invigorates a weakened body (Park et al. 2005b). The main physical ailments for which ginseng is said to be effective include headache, fatigue, dizziness, nausea, asthma, haemorrhage and impotence. It is further said to generally strengthen the viscera, improve resistance to external disease-causing agents and improve the general physical conditions and mental capacity. Ginseng is regarded as adaptogens, substances that strengthen and normalise body functions, helping the body deal with various forms of stress.

Other Uses

Ginseng contains saponins, polyphenols, polyacetylenes, alkaloids and polysaccharides and has recently been used by adding the leaf, stem and berry extracts to cosmetics and soaps and by adding the plant to feed (Choi et al. 2009). Studies found that extruded white ginseng extract had a good potential to be incorporated into alginate to make antioxidant biodegradable film or coating for various food applications (Norajit et al. 2010).

Comments

Two forms of ginseng are marketed – "white ginseng" and "red ginseng" White ginseng is harvested after 4–6 years and then peeled and dried to reduce the water content to 12 % or less. "Red" ginseng is harvested after 6 years, is not peeled and is steam cured and dried, thereby giving them a glossy reddish-brown colouring. Red ginseng contains all the saponins so far isolated from white ginseng and others which are probably formed during the steaming process.

The study of Liberti and Der Marderosian (1978) found a wide variation among commercial ginseng products and the need for more rigid control. Panaxoside patterns of slurry-filled capsules and root extracts most closely resembled those of whole ginseng roots. Tablets did not contain detectable panaxosides while teas and granules for infusion yielded only low concentrations.

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Asparagus cochinchinensis

Scientific Name

***Asparagus cochinchinensis* (Lour.) Merr.**

Synonyms

Asparagus cochinchinensis (Lour.) Merr. var. *longifolius* F. T. Wang and T. Tang, *Asparagus dauricus* Link var. *elongatus* Pampanini, *Asparagus falcatus* (Benth.), *Asparagus gaudichaudianus* Kunth, *Asparagus insularis* Hance, *Asparagus lucidus* Lindl., *Asparagopsis sinica* Miquel, *Asparagus sinicus* (Miquel) C. H. Wright., *Melanthium cochinchinensis* Lour.

Family

Liliaceae (also in Amaryllidaceae)

Common/English Names

Chinese Asparagus, Cochinchinese Asparagus, Shiny Asparagus, Wild Asparagus.

Vernacular Names

Chinese: Tian Men Dong
Japanese: Kusa Sugi Kazura, Nangoku Kusa Sugi Kazura, Tachi-Tenmondo
Khmer: Tumpèang
Korean: Cheun Mun Dong
Portuguese: Espargo De Jardim
Russian: Sparzha Blestiashchaia
Taiwan: Tian Men Dong, Chōnmuntong
Vietnam: Thiên Môn Đông, Thiên Môn, Tút Thiên Nam, Tóc Tiên Leo, Dây Tóc Tiên, Mè Nằm, Nằm Săm (Tay), Co Sin Sương (Thai), Sùa Sú Tùng (H'Mong), Dù Mào siam (Dao)

Origin/Distribution

Asia – China, Japan, Korea, Vietnam, Laos

Agroecology

The species occurs on thinly forested slopes, roadsides, waste fields and coastal areas, near sea level to 1,700 m. It thrives in full sun on well-drained, loamy soil but is partially shade tolerant and drought tolerant and can grow in dry, sandy soils.

Edible Plant Parts and Uses

The fusiform tubers are washed to remove the bitterness and the fibrous core removed, and the tubers are then boiled before being consumed (Uphof 1968; Usher 1974; Kunkel 1984). The root tastes like asparagus. Tubers are also eaten

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after preserving in sugar as sweet conserves (Facciola 1990). The fruit has also been reported to be edible.

Botany

A scandent herbaceous perennial, 1–1.5 m tall with tuberous roots in fascicles, rhombiform, straight or curved and long stalked. Stems slender, much branched, smooth. True leaves scale-like, subtending narrow, green leaflike branchlets (cladodes) (Plate 1). Cladodes 1–3 in a fascicle, linear, flat, 1–2 cm long, 1–1.2 mm wide, falcate, aciculate apex and lustrous. Flowers are bisexual, yellowish-white, 6–7 mm long, 1–3, arising from axils of cladodes; pedicels 7–8 mm long, jointed in the middle or above; male and female flowers separate with perianth in six segments; stamens six, filaments arising from base of perianth segments, anthers versatile and the ovary is oblong. Fruit a globose berry, 5–6 mm in diameter, whitish, ripening to red. Seed one, small and black.

Plate 1 Leaflike cladodes of Chinese Asparagus

Nutritive/Medicinal Properties

Studies reported that *Asparagus cochinchinensis* tuberous roots contained free amino acids saponins, phenols, steroids, phytosterols and polysaccharides as the main constituents with an array of pharmacological properties as elaborated below.

The roots were reported to contain many amino acids: asparagine, citrulline, serine, threonine, proline, glycine, alanine, valine, methionine, leucine, isoleucine, phenylalanine, tyrosine, aspartic acid, glutamic acid, arginine, histidine and lysine (Le and Nguyen 1999). Zeng et al. (2011) reported the content of main chemical groups in *A. cochinchinensis* samples from different producing areas in Guizhou as follows: water 8.17–14.03 %, alcohol 63.49–92.67 %, total ash 4.41–4.82 %, total saponin 2.65–4.36 % and amino acid 3.14–6.83 %.

Seven oligosaccharides, a trisaccharide, a tetrasaccharide, a pentasaccharide, a hexasaccharide, an octasaccharide, a nonasaccharide and a decasaccharide, were isolated from *A. cochinchinensis* tuberous roots (Tomoda and Satoh 1974). Determination of components, periodate oxidation, methylation and partial degradation studies provided the evidences that they were neokestose; they possessed nonreducing linear structure made up of 2→1 linked β-D-fructofuranose residues having a neokestose unit on the end of the molecule. Four new polysaccharides, named as Asparagus polysaccharides A, B, C, D, with antitumour activities, were isolated from the tuberous roots (Du and Guo 1990). A polysaccharide, ACP 1, was isolated from the tuberous roots (Li et al. 2000). It was found to be a galactoglucan, containing backbone of 8β-(1→4) linked D-galactopyranosidic and 6α (1→6) linked D-glucopyranosidic linkages, with a glucosyl branch attached to 3 O of a galactosyl residues of the main chain.

Asp-IV, V, VI and VII, the major furostanol oligosides, were isolated from the methanol extract of *Asparagus cochinchinensis* (Konishi and Shoji 1979). The structures of Asp-IV, V, VI and VII were respectively established as 26-*O*-β-D-glucopyranosyl-22-

methoxyfurostane-3β, 26-diol 3-*O*-β-D-xylopyranosyl (1→4)-β-D-glucopyranoside (1); 26-*O*-β-D-glucopyranosyl-22-methoxyfurostane-3β, 26-diol 3-*O*-α-L-rhamnopyranosyl (1→6)-β-D-glucopyranoside (2); 26-*O*-β-D-glucopyranosyl-22-methoxyfurostane-3β, 26-diol 3-*O*-β-D-xylopyranosyl (1→4)-[α-l-rhamnopyranosyl (1→6)]-β-D-glucopyranoside (3); and 26-*O*-β-D-glucopyranosyl-22-methoxyfurostane-3β, 26-diol 3-*O*-[β-D-glucopyranosyl (1→2)] [β-D-xylopyranosyl (1→4)] [α-L-rhamnopyranosyl (1→6)]-β-D-glucopyranoside (4). The aqueous extract of *A. cochinchinensis* yielded a new oligofurostanoside3-*O*-[α-L-rhamnopyranosyl-(1→4)-β- D-glucopyranosyl]-26-*O*-(β- D-glucopyranosyl)-(25 R)-furosta-5,20-diene,-3β,26-diol as well as two known furostanosides, methylprotodioscin and pseudoprotodioscin (Liang et al. 1988). A novel compound, (+)-nyasol, was isolated from *A. cochinchinensis* tubers (Tsui and Brown 1996).

The following compounds were isolated from dried roots of *Asparagus cochinchinensis*: new spirostanol saponin, asparacoside, two new C-27 spirosteroids, asparacosins A and B, a new acetylenic derivative, 3′-methoxyasparenydiol and a new polyphenol, 3′-hydroxy-4′-methoxy-4′-dehydroxynyasol, as well as five known phenolic compounds, asparenydiol, nyasol, 3′-methoxynyasol, 1, 3-*bis*-di-*p*-hydroxyphenyl-4-penten-1-one and *trans*-coniferyl alcohol (Zhang et al. 2004). Three new furostanol oligoglycosides, named aspacochioside A, B and C, together with the known compound 3-*O*-[(α-l-rhamnopyranosyl-(1→4))(β-D-glucopyranosyl)]-26-*O*-[β-D-glucopyranosyl]-(25S)-5β-spirostane-3β-ol were isolated from *Asparagus cochinchinensis* roots (Shi et al. 2004). The structures of the new aspacochiosides were elucidated as 3-*O*-[(α-L-rhamnopyranosyl-(1→4))(β-D-glucopyranosyl)]-26-*O*-[β-D-glucopyranosyl]-(25S) -5β-furostane-3β,22α,26-triol (1), 3-*O*-[(α-L-rhamnopyranosyl-(1→4))(β-D-glucopyranosyl)]-26-*O*-[β-D-glucopyranosyl]-22α-methoxy -(25S)-5β-furostane-3β,26-diol (2) and 3-*O*-[(α-L-rhamnopyranosyl-(1→4))(β-D-glucopyranosyl)]-26-*O*-[β-D-glucopyranosyl]-(25S)-5β-furost-20(22)-en-3β,26-diol (3). Eight compounds were isolated from the chloroform extract of Asparagi Radix, the root of *Asparagus cochinchinensis*, and identified as β-sitosterol; daucosterol; n-ethatriacontanoic acid, palmitic acid; 9-heptacosylene; sarsasapogenin; diosgenin; and 3-*O*-[α-L-rhamnopyranosyl(1–4)]-β-D-glucopyranoside-(25S)-5β-spirostan-3β-ol (XU et al. 2005). The last compound was found to have antifungal and antitumour activities.

A new furostanol saponin, (25S)-26-*O*-β-D-glucopyranosyl-5 -furost-20(22)-en-3β, 15β,26-triol-3-*O*-[α-L-rhamnopyranosyl-(1–4)]-β-D-glucopyranoside, named aspacochioside D along with three known saponins, aspacochioside C, (25S)-5β-spirostan-3β-yl-*O*-[*O*-α-L-rhamnopyranosyl-(1–4)]-β-D-glucopyranoside and pseudoprotoneodioscin, were isolated from *A. cochinchinensis* (Shen et al. 2011). A new norlignan glycoside, named iso-agatharesinoside and its aglycone, iso-agatharesinol, were isolated from *A. cochinchinensis* tuberous roots (Li et al. 2012). Two new furostanol glycosides, aspacochinosides L and M, were isolated from *Asparagus cochinchinensis* roots (Jian et al. 2013a). Three new pregnane glycosides, aspacochinosides N, O, and P, were isolated from *A. cochinchinensis* roots, together with four known furostanol glycosides (Jian et al. 2013b). Five compounds including quercetin, asparagines, sucrose, β-sitosterol-3-*O*-β-D-glucopyranoside and β-sitosterol were isolated from the methanol extract of *A. cochinchinensis* tuber (Hoang and Nguyen 2013).

Antioxidant Activity

ACP 1, a galactoglucan polysaccharide, isolated from the tuberous roots, was found to scavenge superoxide anion(O*2) produced by PMS-NADH-NBT (phenazine methosulfate – reduced nicotinamide adenine dinucleotide – nitro blue tetrazolium) system, to inhibit lipid peroxidation induced by Fe^{2+} ascorbic acid in mouse liver microsome and to antagonise the haemolysis of rat RBC (red blood cells) induced by H_2O_2 (Li et al. 2000). Quercetin, from *A. cochinchinensis*

tuber, exhibited strong antioxidant activity with IC_{50} = 14.52 μg/mL in the 2,2-diphenyl-1-picrylhydrazyl 1,1-diphenyl-2-picrylhydrazyl (DPPH), radical scavenging assay as compared to standard vitamin C with IC_{50} = 10.49 μg/mL (Hoang and Nguyen 2013). *A. cochinchinensis* tuber aqueous extract showed DPPH, nitrite and hydroxyl radicals scavenging activity in a dose-dependent manner (Samad et al. 2014). It also inhibited linoleic acid peroxidation and $Ferric^{3+}$ reducing ability. The levels of phenolic and flavonoid compounds from *A. cochinchinensis* were found to be 459 μg gallic acid equivalent/g (GAE/g) dry mass and 642 μg catechin equivalent/g (CE/g) dry mass, respectively.

Anticancer Activity

Compounds asparacoside, 3′-hydroxy-4′-methoxy-4′-dehydroxynyasol and 3′-methoxynyasol isolated from the roots demonstrated moderate cytotoxicities in a panel comprised of KB (HeLa contaminated carcinoma/papilloma cells), Col-2 (human colon carcinoma cells), LNCaP (androgen-sensitive prostate adenocarcinoma cells), Lu-1 (lung adenocarcinoma cells lung adenocarcinoma cells) and HUVEC (human umbilical vein endothelial cells), with IC_{50} values ranging from 4 to 12 μg/mL (Zhang et al. 2004). Aspacochioside C exhibited moderate cytotoxicity against human tumor cell line, A549, with an IC_{50} value of 3.87 μg/mL (Shen et al. 2011). Ethyl acetate fraction from *A. cochinchinensis* extract was more effective than other fractions; it induced apoptosis of human hepatocellular carcinoma HepG2 (IC_{50} = 72.33 μg/mL), as revealed by apoptotic feature observation, increased capase-3 activity and Poly ADP ribose polymerase cleavage and decreased expression of X-linked inhibitor of apoptosis protein in a dose-dependent manner (Park et al. 2011). Protein levels of autophagy-related molecules, microtubule-associated protein 1 light chain 3 α and beclin 1, appeared to be induced by the fraction, suggesting *A. cochinchinensis* extract exhibited anticancer activity with induction via both apoptosis and autophagy signalling pathways in HepG2 cells. Chun et al. (2011) reported that the ethyl acetate fraction of *A. cochinchinensis* extract exhibited antitumour activity in nude mice xenografted with human hepatocellular carcinoma (HepG2) cells. Treatment with the *A. cochinchinensis* extract significantly reduced tumour growth. The extract significantly increased the number of apoptotic cells in tumours in a dose-dependent manner, whereas cisplatin treatment significantly decreased tumour volumes and increased the number of apoptotic cells and exhibited hepatotoxicity and nephrotoxicity, in contrast to *A. cochinchinensis* treatment. *A. cochinchinensis* was found to possess antitumor activities without associated hepatotoxicity and nephrotoxicity. Quercetin, from *A. cochinchinensis* tuber, exhibited strong cytotoxicity against the HeLa, human cervical cancer cell line with IC_{50} = 5.78 μg/mL, followed by lung cancer cell line (NCI–H460) with IC_{50} = 12.57 μg/mL and liver cancer cell line (Hep-G2) with IC_{50} = 20.58 μg/mL (Hoang and Nguyen 2013). The anticancer activity of quercetin against breast cancer cell line (MCF-7) was recorded with IC_{50} = 31.04 μg/mL.

Hepatoprotective Activity

Aqueous extract of *Asparagus cochinchinensis* roots ameliorated ethanol-induced cytotoxicity in human hepatoma Hep G2 cells (Koo et al. 2000). The extract (1–100 μg/mL) dose dependently inhibited the ethanol-induced tumor necrosis factor-alpha (TNF-alpha) secretion. It (1–100 μg/mL) also inhibited the ethanol and TNF-alpha-induced cytotoxicity. In addition, the extract inhibited the TNF-alpha-induced apoptosis of Hep G2 cells. The results suggested that *A. cochinchinensis* roots may prevent the ethanol-induced cytotoxicity through inhibition of the apoptosis of Hep G2 cells.

Anti-inflammatory Activity

Aqueous extract of *Asparagus cochinchinensis* roots inhibited secretion of tumor necrosis

factor-alpha (TNF-alpha) from primary cultures of mouse astrocytes (Kim et al. 1998). The extract dose dependently inhibited the TNF-alpha secretion by astrocytes stimulated with substance P (SP) and lipopolysaccharide (LPS). Administration of the extract to astrocytes stimulated with both LPS and SP decreased interleukin 1 (IL-1) secretion. The results suggested that the extract may inhibit TNF-alpha secretion by inhibiting IL-1 secretion and that it had an anti-inflammatory activity in the central nervous system.

Separate studies showed that ethanolic extract of *A. cochinchinensis* roots (ACE) inhibited topical oedema in the mouse ear, following administration at 200 mg/kg (i.p.), leading to substantial reductions in skin thickness and tissue weight, inflammatory cytokine production, neutrophil-mediated myeloperoxidase activity and various histopathological indicators (Lee et al. 2009). Additionally, ACE was effective at reducing inflammatory damage induced by chronic TPA (12-*O*-tetradecanoyl-phorbol-13-acetate) exposure and evoked a significant inhibition of vascular permeability induced by acetic acid in mice. The results demonstrated ACE to be an effective anti-inflammatory agent in murine phorbol ester-induced dermatitis and suggested that the compound may have therapeutic potential in a variety of immune-related cutaneous diseases. Aspacochinoside M, from the roots, showed moderate inhibitory effect on NO production in LPS-induced BV-2 microglial cells with IC_{50} value of 32.26 μM (Jian et al. 2013a). Aspacochinosides O and P and a known furostanol glycoside showed significant inhibition on NO production in LPS-induced BV-2 microglial cells with IC_{50} values of 13.51, 4.72 and 63.57 μM, respectively (Jian et al. 2013b).

A. cochinchinensis tuber aqueous extract enhanced the viability of RAW 246.7 cells and reduced the number of lipopolysaccharide (LPS)-induced cell death (Samad et al. 2014). Only 50.8 % of RAW 246.7 cells were viable after being treated with LPS. After treatment with Asparagus extract (0.2, 0. 3, 0.4 and 0.5 mg/mL), the viability of the RAW cells increased to 51.8, 71.1, 80.0 and 92.7 %, respectively. The results indicated that *A. cochinchinensis* tuber had anti-inflammatory activity.

Anti-aging Activity

Polysaccharides and aqueous extracts of *A. cochinchinensis* roots significantly increased the spleen index and the superoxide dismutase (SOD) activity but reduced the malondialdehyde (MDA) content and slowed down the aging process (Xiong et al. 2011). In contrast, feeding with the stem extracts significantly reduced the SOD activity and increased the MDA accumulation in the brain and liver of mice, suggesting that the stem extracts may not be appropriate for treating aging-related diseases.

Antiosteoporotic Activity

The ethanol extract of *A. cochinchinensis* was found to have the potential to prevent bone-related diseases such as osteoporosis by increasing the differentiation of osteoblasts and reducing both the number and activity of osteoclasts (Lee et al. 2008). The extract increased the differentiation and alkaline phosphatase activity of osteoblasts and decreased the number of tartrate-resistant acid phosphatase (TRAP)-positive multinucleated osteoclasts cells and TRAP activity.

Drug Metabolism Activity

Asparagus cochinchinensis, *Rehmannia glutinosa*, *Scrophularia ningpoensis* and *Ophiopogon japonicus* are components of the Chinese herbal drug Tianwang Buxin Wan, and each component was found to have varying effect on CYP450 enzyme in the rat liver (Wu et al. (2011). It was found that *R. glutinosa* and *S. ningpoensis* aqueous extracts decreased the contents of CYP450 and significantly increased the activity of CYP3A and CYP1A2. *A. cochinchinensis* increased content of Cytb5 and increased the activity of CYP2E1 and CYP1A2. *O. japonicus* had no significant difference on the contents of CYP450 and Cytb5 but increased the activities of CYP3A, CYP2E1 and CYP1A2. They found that by inhibiting CYP450 activity to decrease the

metabolism of other drugs, the effect of other functional groups in the compatibility of Tianwang Buxin Wan could be enhanced.

Traditional Medicinal Uses

This plant has been used in traditional Chinese medicine for over 2,000 years (Duke and Ayensu 1985; Samad et al. 2014). The root is harvested when the plant is dormant and is dried for medicinal use. The dried root is antibacterial, antihelminthic, anti-inflammatory, antipyretic, antiseptic, antitussive, diuretic, expectorant, nervine, sialagogue, stomachic, nervous stimulant and tonic (Duke and Ayensu 1985; NPRI-SNU 1998; Le and Nguyen 1999; Samad et al. 2014). *Asparagus cochinchinensis* is a traditional Chinese medicine used for treating lung- and spleen-related diseases (Xiong et al. 2011). Dried root is a tonic with antifebrile, antitussive and diuretic activity (Konishi and Shoji 1979). *A. cochinchinensis* is often used for the treatment of fever, cough, haemoptysis, diabetes, constipation, swollen and throat pain (Jiang et al. 2010). Prolonged usage is recommended for the treatment of impotence. The plant also has a folk history for the treatment of cancer. *Asparagus cochinchinensis* has been traditionally used for the treatment of cancer in Korea and China (Park et al. 2011).

It also has anti-inflammatory activity and may have therapeutic potential in a variety of immune-related cutaneous diseases.

Asparagus cochinchinensis is often decocted with other herbs (*Rehmannia glutinosa*, *Scrophularia ningpoensis*, *Stemona tuberosa*, *Trichosanthes kirilowii*, *Schisandra sinensis*, *Adenophora verticillata*, *Angelica sinensis*, *Panax ginseng* and *Ophiopogon japonicus*) in various medicinal formulations and used in the treatment of a wide range of ailments including pulmonary diseases; impairment of the body fluid; consumptive ailments such as cough, haematemesis, sore throats and constipation; and diabetes mellitus (NPRI-SNU 1998; Le and Nguyen 1999; Wu et al. 2011).

Other Uses

In China, the plant is used as biological pest control against maggots and mosquito larvae (Yang and Tang 1988).

Comments

The plant is usually propagated by removing foot bud clumps from the mother plant and planting them out.

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Cordyline fruticosa

Scientific Name

***Cordyline fruticosa* (L.) A. Chev.**

Synonyms

Aletris chinensis Lam., *Asparagus terminalis* L. (illeg.), *Calodracon heliconiifolia* (Otto and A.Dietr.) Planch., *Calodracon jacquinii* (Kunth) Planch. (illeg.), *Calodracon nobilis* Planch., *Calodracon sieberi* (Kunth) Planch., *Calodracon terminalis* (L.) Planch., *Convallaria fruticosa* L., *Cordyline amabilis* Cogn. and Marchand, *Cordyline baptistii* Cogn. and Marchand, *Cordyline cheesemanii* Kirk, *Cordyline dennisonii* André, *Cordyline densicoma* Linden and André, *Cordyline eschscholziana* Mart. ex Schult. and Schult.f., *Cordyline ferrea* (L.) Endl. (illeg.), *Cordyline fruticosa* var. *ferrea* (L.) R.R.Fernandez, *Cordyline gloriosa* Linden and André, *Cordyline guilfoylei* Linden ex Lem., *Cordyline hedychioides* F.Muell., *Cordyline heliconiifolia* Otto and A.Dietr., *Cordyline hendersonii* Cogn. and Marchand, *Cordyline jacquinii* Kunth (illeg.), *Cordyline javanica* Klotzsch ex Kunth, *Cordyline metallica* Dallière, *Cordyline nobilis* (Planch.) K.Koch, *Cordyline regina* Veitch ex Regel, *Cordyline reali* (Linden and André) G.Nicholson, *Cordyline sepiaria* Seem., *Cordyline sieberi* Kunth, *Cordyline terminalis* (L.) Kunth (illeg.), *Cordyline terminalis* var. *baileyi* F.M.Bailey, *Cordyline terminalis* var. *boryi* Benth., *Cordyline terminalis* var. *hedychioides* (F.Muell.) Baker, *Cordyline terminalis* var. *sepiaria* (Seem.) Benth., *Cordyline terminalis* var. *sieberi* (Kunth) Benth., *Cordyline terminalis* var. *ti* (Schott) Benth., *Cordyline ti* Schott, *Cordyline timorensis* Planch., *Dianella cubensis* A.Rich., *Dracaena alborosea* Baker (inval.), *Dracaena amabilis* auct., *Dracaena argenteostriata* W.Bull, *Dracaena Dracaena baptistii* auct., *aurora* Linden and André, *Dracaena bellula* Linden and André, *Dracaena brasiliensis* Schult. and Schult.f., *Dracaena casanovae* Linden and André, *Dracaena chelsoni* Veitch, *Dracaena cooperi* Regel, *Dracaena coullingii* auct., *Dracaena cuprea* T.Moore, *Dracaena cuprea* L.Linden and Rodigas (illeg.), *Dracaena douceti* auct., *Dracaena esculenta* Regel, *Dracaena ferrea* L. (illeg.), *Dracaena flemingii* Baker (inval.), *Dracaena formosa* Baker (inval.), *Dracaena fraseri* Baker (inval.), *Dracaena gibsonii* Baker (inval.), *Dracaena gloriosa* Linden ex E.Morren, *Dracaena guilfoylei* Veitch ex Regel, *Dracaena hybrida* auct., *Dracaena illustris* Baker (inval.), *Dracaena imperialis* Baker (inval.), *Dracaena inscripta* Baker (inval.), *Dracaena leonensis* Lodd. ex Loudon, *Dracaena lineata* Baker, *Dracaena lutescens* Verschaff., *Dracaena macleayi* Regel, *Dracaena magnifica* Baker (inval.), *Dracaena metallica* W.Bull, *Dracaena neocaledonica* Linden, *Dracaena nobilis* Baker (inval.), *Dracaena porteana* Baker (inval.), *Dracaena pulchella* Baker (inval.),

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Dracaena pulcherrima Baker (inval.), *Dracaena reali* Linden and André, *Dracaena regalis* Baker (inval.), *Dracaena reginae* T.Moore, *Dracaena regis* André, *Dracaena robinsoniana* André, *Dracaena rothiana* Carrière, *Dracaena salviati* Linden, *Dracaena sepiaria* Seem., *Dracaena siamensis* Baker (inval.), *Dracaena spectabilis* Baker (inval.), *Dracaena splendens* Baker (inval.), *Dracaena sulcata* Baker (inval.), *Dracaena terminalis* L., *Dracaena troubetzkoi* Linden and André, *Dracaena utilis* Baker (inval.), *Dracaena warocquei* Linden and André, *Ezehlsia palma* Lour. ex B.A.Gomes, *Taetsia ferrea* Medik., *Taetsia fruticosa* (L.) Merr., *Taetsia fruticosa* var. *casanovae* (Linden and André) Guillaumin, *Taetsia fruticosa* var. *ferrea* Standl., *Taetsia terminalis* (L.) W.Wight (illeg.), *Terminalis fruticosa* (L.) Kuntze

Family

Asparagaceae

Common/English Names

Boundary Marsh, Broadleaf Palm-lilyCabbage Palm, Chinese Fire Leaf, Cordyline, False Palm, Good Luck Plant, Goodluck Plant, Hawaiian Ti, Hawaiian Ti Leaf, Hawaiian Ti Plant, Palm Lily, Polynesian Ti Plant, Ti Plant, Tree Of Kings.

Vernacular Names

Borneo: Idahan, Litik, Sawamg
Brazil: Croton, Cordiline, Coqueiro-De-Vênus, Dracena-Vermelha, Papagaio (Portuguese)
Chinese: Ya Zhu Ma, Zhu Jiao
Czech: Dracinka Krovitá
Colombia: Palmita Roja
Cook Islands: Rau Ti, Ti
Danish: Buskkordyline
Democratic Republic of Congo: Kaharhi (Shi)
Dutch: Limietstruik
Estonian: Põõsas-Tõlvpuu
Fiji: Kokotadamu, Masawe, Qai, Vakota, Vasili, Vasilini Toga, (Fijian), Rauti (Rotuman), Te Rauti (Banaban/Kiribati)
German: Keulenlilie
Hawaiian: Kī, Lā'ī
Indonesia: Andong, Endong (Javanese), Handjuwang Benar, Hanjuwang Berem, Hanjuwang Hedjo (Sundanese), Kayu Urip (Madurese), Senjuang, Tunjun, Hanjuwang, Jeluang (Sumatra)
Ivory Coast: Èssul Ahrana
Malaysia: Deran (Kelabit), Daun Juang-Juang, Jenjuang, Lenjuang, Jejuang, Senjuang
Marquesas: Ti
New Zealand: Ti Pore Ti Kouka, (Maori), Cabbage Tree
Niue: Si, Ti
Papua New Guinea: Kautbu, Kava (Sepik), Si'i (Manus Island), Bauga (Northern Province), Elaivi (Central Province), Ariko, Ta'un (Bougainville)
Philippines: Dang-Nga (Bontok), Kilala (Bicol), Kilaa (Bisaya), Dongla (Ifugao), Danga (Ilocano), Tokorpari (Kapampangan), Baston De San Jose (Spanish), Sagilala, Tungkod-Obispo, Tungkod-Pare (Tagalog)
Polish: Kordylina Krzewiasta
Ponape: Ting
Russian: Dratsena Verkhushechnaia, Kordilina
Samoan: Ti
Solomon Islands: Asikuga
Spanish: Caña De Indio, Croto
Swedish: Bloddracena
Tahitian: Autī
Thai: Ma Pu Mak Mia
Tongan: Si, Si Tongotongo
Tubui: Ti
'***Uvea***: Si
Venezuela: Cana La India
Vietnamese: Huyết Dụ Ti, Huyết Dụ Lá Nhỏ

Origin/Distribution

The species is believed to have originated in Southeast Asia and Papua New Guinea, but was carried throughout much of the Pacific by early Polynesians. It is now widely cultivated and

sometimes naturalised in these areas including northeastern Australia, New Zealand and the Pacific Islands.

Agroecology

Being a tropical species, the plant thrives in a warm and humid environment from the lowlands to the mountainous areas with mean annual temperatures of 18–30 °C. It grows well in well-drained, fertile sandy loams. It grows in full sun or partial shade. Ti plants have been reported to develop best foliage colour in full sun or bright light. Ti plant responds well to regular watering and fertilisers.

Edible Plant Parts and Uses

The rhizomes, leaves, young shoots and seeds are eaten (Hedrick 1972; Ochse and van den Brink 1980; Facciola 1990). The fleshy rhizome contains up to 20 % sugar, mainly fructose, and is used as a natural sweetener in New Zealand and for the production of an alcoholic beverage *okolehao* in Hawaii. The large, sweet, white rhizome of some cultivars are cooked, roasted or baked for up to four days in earthen ovens to be consumed as food, sweets, refreshment or confectionery in Fiji, Papua New Guinea and the Pacific Islands. In Java, the young shoots are cooked and eaten as *lalap* with rice. In the Hawaiian kitchens, food is wrapped into the leaves for cooking. The Maoris in New Zealand eat both the leaves and seeds.

Botany

Plants erect, evergreen shrub growing to 1–3 m high and spread of 1 m, with a strong usually unbranched, slender, woody stem with rings of leaf scars and enlarged tuber-like subterranean rhizomes (Plate 1). Leaves green or variously coloured; variegated with various combinations of red, pink, purple, maroon, yellow, rose, orange, glossy, oblong-lanceolate, elliptic-lanceolate or narrowly oblong; 25–50×5–10 cm, with distinct mid-vein which is raised abaxially; leaf apex is aristate. Petiole 10–30 cm, channelled abaxially, with dilated base clasping stem and other petiole bases (Plates 1, 2, 3). The leaves are clustered in tufts at the top of the woody stems in mature

Plate 1 Ti plant

Plate 2 Ti plant with variegated green leaves

Plate 3 Ti plant with variegated red leaves

plants and well spaced along the stems in younger plants. Panicle 30–60 cm; branches spreading, 6–13 cm, and many flowered. Flowers are sweetly scented, subsessile or shortly pedicellate; subtended by three bracteoles; bracteoles ovate, 2–3 mm, margin broadly membranous, apex cuspidate. Perianth six, reddish, yellowish or bluish purple; tube 5–6 mm; and lobes erect or recurved, nearly as long as tube. Stamens six, yellow, inserted in the throat of the perianth. Fruit reddish, round, three-parted, 1 cm diameter berries, several to many seeded.

Nutritive/Medicinal Properties

Plant Phytochemicals

The constitution of the glucofructan in Ti plant tuber was found to compose of 1 unit of D-glucose and about 13 of D-fructose (Boggs and Smith 1956). The methylated polysaccharide upon hydrolysis yielded 1,3,4,6-tetra-*O*-methyl-D-fructose (4 moles), 1,3,4-tri- *O*-methyl-D-fructose (2 moles), 3,4,6-tri-*O*-methyl-D-fructose (5 moles), 0, 3,4 di-*O*-methyl-D-fructose and 2,3,4-tri-*O*-methyl-D-fructose (1 mole).

Leaves were reported to contain tyramine (Hegnauer 1964), and shikimc and quinic acids (Yoshida et al. 1975). Thymidine was isolated from the plant (Ooi et al. 1993). Steroidal sapogenins of smilagenin {(25*R*)-5β-spirostan-3β-ol}, sarsasapogenin {(25*S*)-5β-spirostan-3β-ol} and 5β-spirostanes were isolated from *C. terminalis* var. *petiolaris* (Blunden et al. 1981). Four cholestane glycosides were isolated from Ti leaves and characterised as (*22S*)-3β,7β,16β,22-tetrahydroxycholest-5-en-1β-yl *β* D-glucopyranoside (1); (*22S*)-3β, 16β,22,25-tetrahydroxycholest-5-en-1β-yl β-D-glucopyranoside (2); (*22S*)-3β, 16β,22,25-tetrahydroxy-5α-cholestan-1*β*-yl *β*-D-glucopyranoside (3); and (*22S*)-16β,22,25-trihydro-xycholest-5-en3 β-yl *O*-α-L-rhamnopyransoyl-(1→2)-*β*-D-glucopyranoside (4) and the aglycone of (1) (22*S*)-cholest-5-ene-1β, 3β,7β,16β,22-pentol.

Antioxidant Activity

Total phenol contents of the methanol leaf extract was determined as 106.2 mg gallic acid equivalent (GAE), and the DPPH radical scavenging activity of the methanol leaf extract was determined as EC_{50} value of 0.135 mg/g ascorbic acid equivalent (Reddy et al. 2011). Encapsulation of the leaf polyphenol extract of 68.1 mg/g in sodium caseinate beads was achieved. The encapsulated extract showed a stable polyphenol content of 72.35 mg/g GAE (mean) for 6 months, decreasing to 60.02 mg/g of GAE at the end of 6 months and to 52.18 mg/g of GAE after 1 year. The encapsulate polyphenol extract showed significant antioxidant activity compared to non-encapsulated extracts. Sodium-caseinate beads were found to be a promising technique for food supplementation with natural antioxidants.

Antimicrobial Activity

Studies reported that the plant possessed antibacterial activity (Ahmed et al. 2003). The methanolic plant extract showed moderate antibacterial activity against *Escherichia coli*, *Shigella boydii*, *Streptococcus pyogenes* and *Staphylococcus epidermis*. The n-hexane soluble fraction showed mild antibacterial activity against *Salmonella typhi*, *Shigella boydii* and *Shigella dysenteriae*, whereas the acetone and chloroform fraction did not show any activity.

Anticancer Activity

An aqueous extract of Cordyline was found to contain thymidine which exhibited antiproliferative activity (Ooi et al. 1993). 10–5M of thymidine inhibited EL4 cell replication and decreased cell viability after 12–24 hours. The effect was highly specific for this nucleoside. Treated cell cultures showed a significant increase in S phase cells and a corresponding decrease in G1 phase cells. A human breast cancer cell line (MCF7) was also growth-inhibited by 10–5M thymidine, but a murine lymphoma cell line (K36) was not.

The aglycone of cholestane glycoside (1), i.e. (22*S*)-cholest-5-ene-1β, 3β,7β,16β,22-pentol, isolated from the leaves, exhibited weak cytotoxic activity against HL-60 leukaemia cells with an IC_{50} value of 15.6 μg/ml compared to etoposide the positive control with IC_{50} of 0.26 μg/ml (Yokosuka et al. 2012). The four cholestane glycosides and aglycone of cholestane glycoside (2) were not cytotoxic to HL-60 cells at sample concentrations of 20 μg/ml.

Traditional Medicinal Uses

In Hawaiian traditional medicine, Ki flowers are combined with other herbal preparations for treatment of nasal growth, for shortness of breath/asthma, for phlegm in the chest and for vomiting. For fever with absence of perspiration, Ki leaves are wrapped about the head and chest. Ki leaves are used as healing apparatus, not as medicines themselves: they were wrapped around warm stones to serve as hot packs, used in poultices and applied to fevered brows. In Hawaii, a hot leaf infusion was used to induce abortion. In Polynesia and Thailand, Ti plant is used for fever, headache and diarrhoea and as disinfectant for wounds in tropical West Africa. In New Guinea, this species is a stimulant and magic plant used to stimulate fierceness of young warriors. The leaf heart and stem have been reported to be efficacious for abortion in Fiji, and the leaves are used as abortifacient in New Caledonia and Vanuatu and as a contraceptive in New Guinea. In Buka, the Solomon Islands, Ti plant is used in a menstrual ceremony.

In the Philippines, it is used for haemoptysis due to pulmonary tuberculosis, premature abortion, excessive menstruation and blood in urine, bleeding due to piles, enteritis-bacillary dysentery and rheumatic bone pains and swelling pain due to sprains. In Peninsula Malaysia, the heated oiled leaves had been prescribed as application to the abdomen for ague and the medicinal bath of the roots prescribed for the same ailment. Leaves and ashes of leaves had been used in various preparations to treat small pox, madness, skin eruptions and joint pains. A leaf prescription, alone and combined with *Lasia*, had been used for treating coughs.

Other Uses

Ti plant is frequently cultivated as hedge plant and ornamental shrub and indoor foliage potted plant with numerous cultivars available in the tropics, many of them selected for green or reddish or purple foliage. It is used as food, medicinal plant, fibre crop and for magical purposes. Ti foliage is extensively used for flower arrangement and decorative displays and used as food wrappings. Its leaves are used to thatch the roofs of houses and to wrap and store food. The leaves are used as thatch, rain capes and symbols of status, plates, instruments and cups; the stem is used in divining. Leaves are knotted together as measure for houses building. Ti leaves are also used to make items of clothing including skirts worn in dance performances. The Hawaiian hula skirt is a dense skirt, an opaque layer of at least 50 green leaves with the bottom (top of the leaves) shaved flat. The Tongan dance dress, the *sisi*, is an apron of about 20 leaves, worn over a tupenu and decorated with some yellow or red leaves. Ti leaves are also used to make lei and to outline borders between properties. To this day, some Hawaiians plant Ti near their houses to bring good luck. The leaves are also used for lava sledding. A number of leaves are lashed together and people ride down hills on them.

Ti plant represents a symbol of purity and spiritual power in ancient (and modern) Hawai'i. In ancient Hawaii, Ti was thought to have great spiritual power; only high priests and chiefs were able to wear leaves around their necks (healer's leis) during certain ritual activities and used in ceremonial blessings. It was often grown at temples of the medicine god Lono and the hula goddess Laka. Temples to Lono were thatched with lā'ī leaves and those to Kü (the war god) were thatched with other plants. In Malaysia, green and red Ti plants had been used in occult and magic to keep away evil spirits. Red-leaved Ti plants had been hung over the head of women

during confinement to keep away evil spirits. A sick man may be stroked with a bunch of Ti leaves to purge out mischievous spirits from him and may be carried when elephant hunting as a protection. Among the dayaks in East Malaysia, Ti plants were planted where propitiatory offerings were placed to attract good spirits. Also shoots had been placed in water in a spirit-summoning ceremony in Kelantan.

Comments

Ti plant is really propagated from stem sections, terminal stem cuttings and seeds and by air layering. Ray et al. (2013) described an efficient and rapid micropropagation method for large-scale multiplication of *Cordyline terminalis* in a cost-effective manner. Thousands of micropropagated plants were produced within 4–5 months using this protocol.

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Ophiopogon japonicus

Scientific Name

***Ophiopogon japonicus* (L.f.) Ker- Gawl.**

Family

Asparagaceae

Synonyms

Anemarrhena cavaleriei H.Lév. (illeg.), *Convallaria graminifolia* Salisb., *Convallaria japonica* L.f., *Convallaria japonica* Thunb. (basionym), *Flueggea anceps* Raf., *Flueggea angulata* Raf. (illeg.), *Flueggea japonica* (Thunb.) Rich., *Liriope gracilis* (Kunth) Nakai, *Mondo gracile* (Kunth) Koidz., *Mondo gracile* var. *brevipedicellatum* Koidz., *Mondo japonicum* (Thunb.) Farw., *Mondo longifolium* Ohwi, *Mondo stolonifer* (H.Lév. & Vaniot) Farw., *Ophiopogon argyi* H.Lév. *Ophiopogon chekiangensis* Koiti Kimura & Migo, *Ophiopogon gracilis* Kunth, *Ophiopogon gracilis* var. *brevipedicellatus* (Koidz.) Nemoto, *Ophiopogon japonicus* var. *caespitosus* Okuyama, *Ophiopogon japonicus* var. *elevatus* Kuntze, *Ophiopogon japonicus* var. *umbrosus* Maxim., *Ophiopogon merrillii* Masam., *Ophiopogon ohwii* Okuyama, *Ophiopogon stolonifer* H.Lév. & Vaniot, *Polygonastrum compressum* Moench, *Slateria coerulea* Siebold ex Miq., *Slateria japonica* (Thunb.) Desv., *Tricoryne acaulis* D.Dietr., *Tricoryne caulescens* D.Dietr.

Common/English Names

Dragon's Beard, Dwarf Lily turf, Fountain Plant, Mondo Grass, Japanese Lily Turf, Japanese Snake's Beard, Liriopogon, Monkey Grass, Ophiopogon, Snake's Beard

Vernacular Names

Brazil: Grama Preta
Chinese: Mai Dong, Mai Men Dong
Czech: Sedoulek Japonský
Danish: Japansk Slangeskæg
Dutch: Japanse Slangenbaard, Ophiopogonus
French: Herbe Aux Turquoises, Muguet Du Japon, Ophiopogon
German: Japanischer Schlangenbart
Japanese: Ja-No-Hige, Ryu-No-Hige
Korean: Jobnipmaekmundongajaebi
Philippines: Langigit
Portuguese: Grama-Preta, Ofiopógão-Do-Japão, Pêlo-De-Urso
Russian: Ofiopogon Japonskij
Swedish: Ormskägg

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Vietnamese: Mạch Đông, Mach Món, Mach Môn Dông, Tóc Tiên, Lan Tiên, Xà Thảo, Duyên Giới Thảo, Phiếc Kép Phạ (Tay)

Origin/Distribution

The plant is native to East Asia – China (Anhui, Fujian, Guangdong, Guangxi, Guizhou, Hebei, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Shaanxi, Shandong, Sichuan, Yunnan, Zhejiang), Japan (Hokkaido, Honshu, Kyushu, Shikoku), Korea, Taiwan and the Philippines – Luzon (Benguet Province) and Mindanao (Mt. Apo).

Agroecology

In its natural habitat, it occurs in shady places in lowland and foothills, forests, dense scrub in ravines, moist and shady places on slopes and along streams, cliffs at elevations of 200–2,800 m in East Asia. It grows well in full sun or partial shade in well-drained, moist sandy or sandy-loam soils with a pH between 6.5 and 7.5.

Edible Plant Parts and Uses

The plant is more widely known as a medicinal herb than a food plant. Tuberous root is edible (Usher 1974) and eaten as a famine food (Read 1946). The root is used as food ingredient in Taiwan and as functional food in China often as a substitute for ginseng. *O. japonicus* is a traditional medicine, admitted as one of functional food ingredient by the Ministry of Health of the People's Republic of China (Liang et al. 2012). The root is considered aromatic, sweet (Stuart 1979) and mucilaginous (Duke and Ayensu 1985), but other reports say that the bitterness has to be removed before consumption (Tanaka 1976; Kunkel 1984).

Botany

An evergreen, tuft-forming stoloniferous perennial. Stolons creeping, slender, roots moderately thick, usually with tuberous part near middle or tip. Leaves basal, sessile, fasciculate, linear, generally 15–50 cm long by 2–4 mm, 3–7 parallel veined, margin serrulate, dark green above, pale glaucous beneath (Plate 1). Scape 6–15 (–27) cm, much shorter than leaves. Inflorescence in axillary racemes, 1–20 cm long, several to more than 10 flowered with lanceolate white bracts. Flowers solitary or paired, usually pendant; pedicel 34 mm. Tepals 6-lobed, white or pale lilac, lanceolate, 5×2 mm. Filaments very short; anthers 2.53 mm, lanceolate. Style narrowly conical, 4 mm, moderately thick, basally widened. Berry subglobose to ellipsoid–globose, blue violet, 5–9 mm in diameter. Seeds globose 6–8 mm.

Plate 1 A dense clump of *Ophiopogon japonicus*

Nutritive/Medicinal Properties

Tuberous Root Nutrient/ Phytochemicals

The root was reported to contain about 1.6 % protein, 0.5 % fat, 80 % carbohydrate, 2.3 % ash (Read 1946), mucilage, sugars, β-sitosterol, ophiopogonin A, ophiopogonin B and ophiogonone A (Le and Nguyen 1999), minerals N, P, K (Chen et al. 2005); Ni, Zn, Mn, Cu, Mg, Fe, Ca and Pb (Lou and Xu 2007).

Steroidal Saponins and Glycosides

Four steroidal glycosides, named ophiopogonins A, B, C and D, were isolated from the rhizome (Kato et al. 1968). The structure of ophiopogonin B from the tubers was established as ruscogenin (1)-α-L-

rhamnopyranosyl ($1_{rham}\rightarrow2_{fuc}$)-β-D-fucopyranoside (Tada and Shoji 1972). The chemical structure of ophiopogonin D, a glycoside isolated from *O. japonicus* tuber, was established as ruscogenin (1)-[α-L-rhamnopyranosyl($1_{rham}\rightarrow2_{fuc}$)] [D-xylopyranosyl($1_{xyl}\rightarrow3_{fuc}$)]-β-D-fucopyranoside (Tada et al. 1973). The following minor oligosides were isolated from the tubers: ophiopogonin A = ruscogenin 1-*O*-[(3-*O*-acetyl)-α-L-rhamnopyranosyl (1→2)]-β-D-fucopyranoside; ophiopogonin B' = diosgenin 3-*O*-[(4-*O*-acetyl)-α-L-rhamnopyranosyl (1→2)] [β-D-xylopyranosyl (1→3)]-β-D-glucopyranoside; ophiopogonin C = mono-*O*-acetylophiopogonin D; ophiopogonin C' = diosgenin 3-*O*-α-L-rhamnopyranosyl (1→2)-β-D-glucopyranoside (=prosapogenin A of dioscin); and ophiopogonin D' = diosgenin 3-*O*-[α-L-rhamnopyranosyl-(1→2)] [β-D-xylopyranosyl (1→3)]-β-D-glucopyranoside (Watanabe et al. 1977). Two borneol glycosides, L-borneol-β-D-glucoside and L-borneol 6-*O*-β-D-apiosyl- β -D-glucoside, were isolated from the roots (Kaneda et al. 1983). A steroidal sapogenin named ophiogenin with the structure 25R-spirost-5-en-3β, 14α, 17α-triol was isolated (Nakanishi and Kameda 1987). The following compounds were isolated from *O. japonicus*: diosgenin 3- *O*-[(2- *O*-acetyl)-α-L-rhamnopyranosyl (1→2)]β-D-xylopyranosyl (1→3)]-β-D-glucopyranosyl, ruscogenin 1-*O* -[α-L-rhamnopyranosyl(1→3)][β-D-xylopyranosyl (1–3)] β-D-glucopyranosyl, L-borneol 6-*O*-β-D-apifuranosyl (1→6)β-D-glucopyranosyl, diosgenin 3-*O*-[α-L-rhamnopyranosyl (1→2)[β-D-xylopyranosyl (1→3)]-β-D-glucopyranosyl and diosgenin-3-*O*-[α-L-rhamnopyranosyl (1→3)β-D-glucopyranosyl (Yang et al. 1987b). Two terpenoid glycosides ophiogenin 3-*O*-α-L-rhamnopyranosyl-(1→2)-β-D-glucopyranoside and bornyl 7-*O*-α-L-arabinofuranosyl(1→6)-β-D-glucopyranoside were isolated from *O. japonicus* roots (Adinolfi et al. 1990). Two monoterpene glycosides L-borneol *O*-β-D-glucopyranoside and L-borneol *O*-β-D-apiofuranosyl (1→6)-β-D-glucopyranoside and eight steroidal glycosides ophiopogonin B, (25*S*)-ruscogenin 1-*O*-α-L-rhamnopyranosyl(1→2)-β-D-fucopyranoside = glycoside C, ophiopogonin D, (25*S*)-ruscogenin 1-*O*-[α-L-rhamnopyranosyl(1→2)] [β-D-xylopyranosyl(1→3)]-β-D-fucopyranoside = Ls-10, ruscogenin 1-*O*-sulfate, (23*S*,24*S*,25*S*)-23,24-dihydroxyruscogenin 1-*O*-[α-L-rhamnopyranosyl(1→2)] [β-D-xylopyranosyl (1→3)]-α-L-arabinopyranoside 24-*O*-β-D-fucopyranoside, (23*S*, 24*S*, 25*S*)-23,24-dihydroxyruscogenin I-*O*-[α-L-2,3,4-tri-*O*-acetylrhamnopyranosyl(1→2)] [β-D-xylopyranosyl(1→3)]-α-L-arabinopyranoside 24-*O*-β-D-fucopyranoside and (23*S*,24*S*,25*S*)-23,24-dihydroxyruscogenin 1-*O*-[α-L-2,3,4-tri-*O*-acetylrhamnopyranosyl(1→2)] [β-D-xylopyranosyl(1→3)]-α-L-arabinopyranoside 24-*O*-β-D-fucopyranoside (Asano et al. 1993b).

A steroidal saponin with the following structure (25*S*)-1-*O*-β-D-fucopyranosyl-3-*O*-α-L-rhamnopyranosylruscogenin was isolated from *Ophiopogon japonicus tuber* (Branke and Hashilinger 1995). Two new C27 steroidal glycosides designated cixi-ophiopogons A and B with respective structures 3-*O*-α-L-rhamnopyranosyl (1→2) [β-D-xylopyranosyl (1→3]-β-D-glucopyranoside and ophiogenin 3-*O*-α-L-rhamnopyranosyl (1→2) [β-D-xylopyranosyl (1→3][β-D-glucopyranosyl (1→4)]-β-D-glucopyranoside together with a known ophiogenin 3-*O*-α-L-rhamnopyranosyl (1→2)-β-D-glucopyranoside were isolated from the tubers (Chen et al. 2000). Four known glycosides, L-borneol-*O*-β-D-glucopyranoside, (1), L-borneol-*O*-[β-D-apiofuranosyl(1→6)]-*O*-β-D-glucopyranoside, 4-allyl-1,2-benzenediol-1-*O*-L-rhamnopyranosyl(1→6)-*O*-β-D-glucopyranoside and (22S)- cholest-ene-1β,3β,16β,22-tetrol-1-*O*-α-L-rhamnopyranosyl-16-*O* β-D-glucopyranoside, were isolated from *Ophiopogon japonicus* tubers (Dai et al. 2000a). Two new C_{27} steroidal glycosides, named ophiopojaponins A and B were isolated from the tubers, and their structures elucidated, respectively, as pennogenin 3-*O*-[2′-*O*-acetyl-α-L-rhamnopyranosyl(1→2)]-β-D-xylopyranosyl(1→3)-β-D-glucopyranoside and (25R)-3β,14α,22ξ,26-tetrahydroxyfurost-5-ene-3-O-[α-L-rhamnopyranosyl-(1→2)- β-D-glucopyranoside]-26-*O*-β-D-glucopyranoside (Dai et al. 2000b). A new steroidal glycoside, named ophiopojaponin C with the structure ophiopogenin 3-*O*-[α-L-rhamnopyranosyl (1→2)]-β-D-xylopyranosyl(1→4)-β-*D*-glucopyranoside, and two known ones, diosgenin 3-*O*-[2-*O*-acetyl-α-L-rhamnopyranosyl(1→2)]-β-

D-xylopyranosyl(1→3)-β-*D*-glucopyranoside and ruscogenin 1-*O*-[2-*O*-acetyl-α-L-rhamnopyranosyl (1→2)]-β-*D*-xylopyranosyl(1→3)-β-*D*-fucopyranoside, were isolated from *O. japonicus* (Dai et al. 2005). A new steroidal saponin, named ophiopogonin E with the structure pennogenin 3-*O*-β-D-xylopyranosyl (1→4)-β-D-glucopyranoside, was isolated from the tubers along with five known steroidal saponins: pennogenin 3-*O*-[2′-*O*-acetyl-*α*-L-rhamnopyranosyl (1→2)-β-*D*-xylopyranosyl(1→3)-β-D-glucopyranoside, 25(*R*)-ruscogenin 1-*O*-[α-L-rhamnopyranosyl (1→2)][β-D-xylopyranosyl(1→3)]-β-D-fucopyranoside, 25-(*R*)-ruscogenin, diosgenin 3-*O*-[2-*O*-acetyl-α-L-rhamnopyranosyl(1→2)][β-D-xylopyranosyl(1→3)]-β-D-glucopyranoside and diosgenin 3-*O*-[α-L-rhamnopyranosyl(1–2)][β-D-xylopyranosyl(1→3)]-β-D-glucopyranoside (Cheng et al. 2006). A new furospirostanol saponin, ophiofurospiside B, was isolated from *O. japonicus* (Xu et al. 2007). A new furospirostanol saponin, ophiofurospiside A with the structure 26-*O*-β-D-glucopyranosyl-(22S, 25R)-furospirost-5-ene-3β, 17α, 26-triol-3-*O*-[α-L-rhamnopyranosyl-(1→2)]-[β-D-xylopyranosyl-(1→4)]-glucopyranoside, was isolated together with three known steroidal glycosides 2–4 from the tubers (Xu et al. 2008a). A new C_{27}-steroidal glycoside,pennogenin-3-*O*-α-L-rhamnopyranosyl-(1→2)-β-D-xylopyranosyl-(1→4)-β-D-glucopyranoside, along with three known compounds pennogenin-3-*O*-α-L-rhamnopyranosyl-(1→2)-β-D-glucopyranoside, ophiopojaponin C and ophiopogonin D, was isolated from the tuber (Wang et al. 2008). Two new steroidal glucosides, 26-*O*-β-D-glucopyranosyl (25*S*)-furost-5-ene-1β,3β, 22α,26-tetraol 1-*O*-β-D-xylopyranosyl-(1→3)-[α-L-rhamnopyranosyl-(1→2)]-β-D-fucopyranoside and (25R) spirost-5-ene-3β,14α-diol-3-β-*O*-β-L-rhamnopyranosyl(1→2)-[β-D-xylopyranosyl(1→4)]-β-D-glucopyranoside, were isolated from the *Ophiopogon japonicus* (Xu et al. 2008b).

Two novel furostanol saponins, ophiopogonin F and ophiopogonin G, were isolated from the fresh tubers and their chemical structures assigned as (25R)-26-[(*O*-β-D-glucopyranosyl-(1→2)-β-D-glucopyranosyl)]-22α-hydroxyfurost-5-ene-3-*O*-β-D-xylopyranosyl-(1→4)-*O*-[α-L-rhamnopyranosyl-(1→2)]-β-D-glucopyranosideand(25R)-26-[(*O*-β-D-glucopyranosyl-(1→6)-β-D-glucopyranosyl)]-22α-hydroxyfurost-5-ene-3-*O*-β-D-xylopyranosyl-(1→4)-*O*-[α-L-rhamnopyranosyl-(1→2)]-β-D-glucopyranoside respectively (Zhang et al. 2009). Three steroidal saponins, (25*R*)-ruscogenin-3-yl α-L-rhamnopyranosyl-(1→2)-[β-D-xylopyranosyl-(1→4)]-β-D-glucopyranoside, diosgenin-3-yl2-*O*-acetyl-α-L-rhamnopyranosyl-(1→2)-[β-D-xylopyranosyl-(1→4)]-β-D-glucopyranosideandpennogenin-3-yl2-*O*-acetyl-α-L-rhamnopyranosyl-(1→2)-[β-D-xylopyranosyl-(1→4)]-β-D-glucopyranoside (Duan et al. 2010a), and two new furostanol glycosides, ophiopogonins H and I, with respective structures (25*R*)-26-[(*O*-β-D-glucopyranosyl-(1→2)-β-d-glucopyranosyl)]-22α-hydroxyfurost-5-ene-3-*O*-[α-L-rhamnopyranosyl-(1→2)]-β-D-glucopyranosideand(25*R*)-26-[(*O*-β-D-glucopyranosyl-(1→2)-β-*D*-glucopyranosyl)]-20α-hydroxyfurost-5,22-diene-3-*O*-[α-L-rhamnopyranosyl-(1→2)]-β-D-glucopyranoside (Duan et al. 2010b), were isolated from the fibrous roots. A new steroidal glycoside, (25*R*)-14α, 17α-hydroxyspirost-5-en-3β-yl3-*O*-α-L-rhamnpyranosyl-(1→2)-β-D-glucopyranosyl-(1→3)-β-D-glucopyranoside, together with three known steroidal glycosides,(25*R*)-3β-hydroxyspirost-5-en-1β-yl-3-*O*-α-L-rhamnopyranosyl-(1→2)-*O*-β-D-xylopyranosyl-(1→3)-α-L-arabinopyranoside, cixi-ophiopogon B and cixi-ophiopogon A, were obtained from the tuberous roots (Wang et al. 2011a). The average recoveries of diosgenin and ruscogenin from *O. japonicus* root using non-aqueous capillary electrophoresis were 102 % and 99.2 %, respectively (Huang et al. 2011). The content of diosgenin in the root was 0.018 mg/g and ruscogenin 0.008 mg/g.

Eight novel steroidal saponins, ophiopogonins H–O, along with seven known steroidal saponins were isolated from the tubers (Zhang et al. 2012). Two new furostanol saponins ophiopogonins J and K were isolated from the fibrous roots (Kang et al. 2013). Their structures were established,

respectively, as (25R)-26-*O*-[(β-D-glucopyranosyl-(1→2)-β-D-glucopyranosyl)]-14-hydroxyfurost-5,20(22)-diene 3-*O*-[α-L-rhamnopyranosyl-(→2)]-β-D-glucopyranoside (1) and (25R)-26-*O*-[(β-D-glucopyranosyl-(1→2)-β-D-glucopyranosyl)]-furost-5,20(22)-diene 3-*O*-α-L-rhamnopyranosyl-(1→2)[(β-D-xylopyranosyl-(1→4)-β-D-glucopyranoside)]. A new furostanol glycoside, named ophiopogonin J, was isolated from the fibrous root, and its structure was established as (25*R*)-26-[(*O*-β-D-glucopyranosyl-(1→2)-β-D-glucopyranosyl)]-20α -hydroxyfurost-5, 22-diene-3-*O*-α-L-rhamnopyranosyl-(1→2)-[β-D-xylopyranosyl(1→4)]-β-D-glucopyranoside (Duan et al. 2012).

Four new steroidal saponins, named ophiopogonin P–S (1–4), together with 11 known ones, pennogenin-3-*O*-[2-*O*-acetyl-α-L-rhamnopyranosyl-(1→2)] [β-D-xylopyransoyl-(1→4)]-β-D-glucopyranoside, diosgenin 3-*O*-[2-*O*-acetyl-α-L-rhamnopyranosyl-(1→2)] [β-D-xylopyransoyl-(1→4)]-β-D-glucopyranoside, sprengerinin A, sprengerinC, pennogenin-3-*O*-α-L-rhamnopyranosyl-(1→2)-[β-D-xylopyransoyl-(1→4)]-β-D-glucopyranoside, 14-hydroxy diosgenin 3-*O*-α-rhamnopyranosyl-(1→2)-β-D-glucopyranoside, (25*R*)-spirost-5-,14-dien-3β-yl-*O*-α-L-rhamnopyranosyl-(1→2)- [β-D-xylopyransoyl-(1→4)]-β-D-glucopyranoside, ophiogenin 3-*O*-α-rhamnopyranosyl-(1→2)-β-D-glucopyranoside, ophiopojaponin C, 14-hydroxydiosgenin 3-*O*-α-L-rhamnopyranosyl-(1→2)- β-D-glucopyranoside and ophiopogonin D, were isolated from the tuberous roots (Li et al. 2013). Two new furostanol saponins elucidated as (25R)-26-O-[β-d-glucopyranosyl-(1 → 2)-β-d-glucopyranosyl]-5-ene-furost-1β,3β,22α,26-tetraol-3-O-α-l-rhamnopyranosyl-(1 → 2)-[β-d-xylopyranosyl-(1 → 4)]-β-d-glucopyranoside (ophiopogonin P) and (25R)-26-O-[β-d-glucopyranosyl-(1 → 6)-β-d-glucopyranosyl]-5-ene-furost-1β,3β,22α,26-tetraol-3-O-α-l-rhamnopyranosyl-(1 → 2)-[β-d-xylopyranosyl-(1 → 4)]-β-d-glucopyranoside (ophiopogonin Q) were isolated from the tubers (Guo et al. 2013). Nolinospiroside F, a steroidal saponin, was isolated from *O. japonicus* (Sun et al. 2013).

Homoisoflavonoids

Four new homoisoflavonoids were isolated from the tubers: methylophiogonanone A, methylophiogonanone B, methylophiogononone A and methylophiogononone B (Tada et al. 1980). Their structures were established as 5,7-dihydroxy-6,-8-dimethyl-3-(3,4-methylenedioxybenzyl)-chroman-4-one; 5,7-dihydroxy-6,-8-dimethyl-3-(3,4-methoxybenzyl)-chroman-4-one;5,7-dihydroxy-6,-8-dimethyl-3-(3,4-methylenedioxybenzyl)-chromane; and 5,7-dihydroxy-6,-8-dimethyl-3-(4-methoxybenzyl)-chromane, respectively. Eight compounds were isolated from the roots including the known homoisoflavanoids (methylophiopogonanone A, methylophiopogonanone B, ophiopogonanone A), two other homoisoflavonoids, an amide compound and two borneol glycosides (Kaneda et al. 1983). Two homoisoflavones 6-aldehydo-isoophiopogonone A and 6-aldehydo-isoophiopogonone B were isolated from the roots (Zhu et al. 1987b). Five homoisoflavonoids: 6-aldehydo-isoophiopogonanone A, methylophiopogonanone A and methylophiopogonanone B and two new homoisoflavones, named 6-aldehydo-isoophiopogonone A and 6-aldehydo-isoophiopogonone B, were isolated from tubers (Zhu et al. 1987a). The following compounds were isolated from the tuber: homoisoflavonoids methylophiopogonone A, ophiopogonone A, methylophiopogonanone A, ophiopogonanone A, [5,7-dihydroxy-3-(4′-hydroxybenzyl)-6-methylchromone] = JE-III, desmethylisoophiopogonone B, 5, 7, 2′-trihydroxy-6-methyl-3-(3′, 4′-methylenedioxybenzyl)chromone,5,7,2′-trihydroxy-8-methyl-3-(3′, 4′-methylenedioxybenzyl)chromone and a racemate of 5-hydroxy-7, 8-dimethoxy-6-methyl-3-(3′,4′-dihydroxybenzyl)chroman-4-one (Asano et al. 1993a). Five new homoisoflavonoids, ophiopogonanone C, ophiopogonanone D, ophiopogonone C, ophiopogonanone E and ophiopogonanone F and six known compounds were isolated from an ethanol extract of the tubers (Chang et al. 2002). From the ethyl acetate extract of the tuberous roots of *O. japonicus*, eight known and five new homoisoflavonoid compounds were isolated (Nguyen et al. 2003). The new compounds were 5,7-dihydroxy-8-methoxy-6-methyl-3-(2′-

hydroxy-4′-methoxybenzyl)chroman-4-one, 7-hydroxy-5,8-dimethoxy-6-methyl-3-(2′-hydroxy-4′-methoxybenzyl)chroman-4-one, 5,7-dihydroxy-6,8-dimethyl-3-(4′-hydroxy-3′-methoxybenzyl)chroman-4-one,2,5,7-trihydroxy-6,8-dimethyl-3-(3′,4′-methylenedioxybenzyl) chroman-4-oneand2,5,7-trihydroxy-6,8-dimethyl-3-(4′-methoxybenzyl)chroman-4-one. Twenty-five homoisoflavonoids were isolated from the tubers, and 18 were characterised: 5,3′,4′-trihydroxy-7-methoxy-8-methylhomoisoflavanone,5,2′-dihydroxy-7,8,4′-trimethoxy-6-methyl homoisoflavanone, 5-hydroxy-7,4′-dimethoxy-6,8-dimethyl homoisoflavone, 5,7,4′-trihydroxy-3′,5′-dimethoxy-6,8-dimethyl homoisoflavanone, 5-hydroxy-3′,4′-dimethoxy-6,8-dimethyl homoisoflavanone, 5,4′-dihydroxy-7,3′-dimethoxy-8-methyl homoisoflavanone,ophiopogonanoneE,5-hydroxy-7-methoxy-3′,4′-methylenedioxy-6,8-dimethyl homoisoflavanone, ophiopogonanone A, 5,7-dihydroxy-4′-methoxy-6-methyl homoisoflavanone, methylophiopogonone A, methylophiopogonanone A, ophiopogonanone F, methylophiopogonanone B, 6-aldehydo-isoophiopogonone A, 6-aldehydo-isoophiopogononeBand5,7-dihydroxy-4′-methoxy-6-aldehydo-8-methyl homoisoflavonanone (Ye et al. 2005b). Ye et al. (2005a) found that the homoisoflavonoid content of 3 principal homoisoflavonoids, methylophiopogonanone A, methylophiopogonanone B and 6-aldehydo-isoophiopogonanone A, of *O. japonicus* varied significantly from species to species and from locality to locality. Seven homoisoflavones, namely, methylophiopogonanone A, methylophiopogonanone B, methylophiopogonone A, methylophiopogonone B, 2′-hydroxy-methylophiopogonone A, 6-aldehydo-isoophiopogonanone A and 5,7-dihydroxy-8-methoxy-6-methyl-3-(2′ hydroxyl- 4′- methoxybenzyl)chroman- 4-one, were isolated from the tubers (Cheng et al. 2005a). Two new homoisoflavonoids ophiopogonone D and ophiopogonanone G were isolated from the fibrous roots (Duan et al. 2009). Three homoisoflavonoid compounds including methylophiopogonanone A, 6-aldehydo-isoophiopogonone A and 6-formyl-isoophiopogonanone A, were successfully isolated from *O. japonicus* and purified using combination of supercritical fluid extraction and high-speed countercurrent chromatography (Ma et al. 2009). In the operation, 140 mg crude extracts was separated and yielded 15.3 mg of methylophiopogonanone A (96.9 % purity), 4.1 mg of 6-aldehydo-isoophiopogonone A (98.3 % purity) and 13.5 mg of 6-formyl-isoophiopogonanone A (97.3 % purity). The mean recoveriesofthreehomoisoflavonoids,6-aldehydo-3-ophiopogonanone A, methyl ophiopogonanone A and ophiopogonanone A from *Ophiopogon japonicus* by HPLC were 99.41–99.86 % (RSD 0.82–1.05 %) (Zeng et al. 2012). The linear response ranges of. 6-aldehydo-3-ophiopogonanone A, methyl ophiopogonanone A and ophiopogonanone A were 0.165–0.990 μg (R^2=0.999 9), 0.153–0.918 μg (r=0.999 9) and 0.270–1.620 μg (R^2=0.999 9), respectively.

Ten homoisoflavonoids isolated from *O. japonicus* extracts were identified as methylophiopogonanone A (1), methylophiopogonanone B (2), ophiopogonanone A (3), ophiopogonanone E (4), 5, 7-dihydroxy-6, 8-dimethyl-3-(4′-hydroxy-3′, 5′-methoxybenzyl) chroman-4-one (5), methylophiopogonone A (6), methylophiopogonone B (7), desmethylisoophiopogonone B (8), 5, 7, 2′-trihydroxy-8-methyl-3-(3′, 4′-methylenedioxybenzyl)chromone(9)and5,7,2′-trihydroxy-6, 8-dimethyl-3-(3′, 4′-methylenedioxybenzyl) chromone (Zhou et al. 2008a). Homoisoflavanones isolated from the tuberous roots were identified as (3*R*)-2,3-dihydro-7-hydroxy-5-methoxy-3-(4-methoxybenzyl)-6,8-dimethyl-4*H*-chromen-4-one,(3*R*)-3-(1,3-benzodioxol-5-ylmethyl)-2,3-dihydro-7-hydroxy-5-methoxy-6,8-dimethyl-4H-chromen-4-one, (3*R*)-3-(1,3-benzodioxol-5-ylmethyl)-2,3-dihydro-7-hydroxy-5-methoxy-6-methyl-4*H*-chromen-4-one and ophiopogonanone A (Wang et al. 2010b). Two new homoisoflavonoids, named ophiopogonone E and ophiopogonanone H, together with 13 known ones, namely, 5,7,2′-trihydroxy-3′,4′-methylenedioxy-6,8-dimethyl homoisoflavone, 5,7,4′-trihydroxy-3′-methoxy-6,8-dimethyl homoisoflavanone, 5,7-dihydroxy-4′-methoxy-6-methyl homoisoflavanone,methylophiopogonanoneB,5,7,2′-trihydroxy-4′-methoxy-6,8-dimethyl homoisoflavanone ophiopogonanone A, methylophiopogonanone A, methylophiopogonone A, ophiopogonanone E, 5,7,2′-trihydroxy-3′,4′-methylenedioxy-8-methyl homoisoflavone, 7,2′-dihydroxy-5,8,4′-

trimethoxy-6-methyl homoisoflavanone, 5,7,4′-trihydroxyhomoisoflavone and 5,7,4′-trihydroxy-6-methyl homoisoflavanone, were isolated from the tuberous roots (Li et al. 2012a). One novel spirostan, named ophiogenin, together with six known spirostans, and one new sesquiterpene glycoside, named ophioside A together with one known monoterpene glycoside, were isolated from the active fractions of *Ophiopogon japonicus* roots (Lan et al. 2013). The aglycone of ophioside A named ophiopogonol was obtained from acid hydrolysis of ophioside A. Thirteen homoisoflavonoids, including three new ones 8-formyl-7-hydroxy-5,4′-dimethoxy-6-methyl-homoisoflavone, 6-formylisoophiopogonone B and 8-formylophiopogonanone B, were isolated (Zhou et al. 2013). The structure of the formerly reported "6-aldehydo-isoophiopogonone B" was revised to 8-formylophiopogonone B. Two homoisoflavonoids (methylophiopogonanones A and B) were used as markers in the quality control of Radix Ophiopogonis in Shengmai injection (Wang et al. 2013).

Polysaccharides/Lectins

Md-1 and Md-2 polysaccharides from *O. japonicus* were found to be glucosans, consisting of D-glucose units joined by alpha-(1→4) glucosidic linkages and with molecular weight of 27,064 and 48,651, respectively (She and Shi 2003). Radix Ophiopogonis polysaccharide (ROP or MDG-1), a natural graminan-type fructan with weight average molecular weight (M_w) of ~5 kDa, was isolated (Lin et al. 2005; Zheng et al. 2007, 2009; Wang et al. 2010a). The water-soluble β-D-fructan (MDG-1) was isolated from *O. japonicus* (Xu et al. 2005; Wang et al. 2010a, 2012a; Zhu et al. 2014) A fructan, Opaw-2, with molecular mass of about 14 kDa, was isolated from the tuberous roots of *O. japonicus* (Wu et al. 2006). Opaw-2 comprised of fructose and glucose with a molar ratio of 30:1. Opaw-2 possessed a backbone structure of beta-(1→2)-Fruf and beta-(2→6)-Fruf residues that branched at O-6 of beta-(1→2)-Fruf residues with alpha-1-linkage to the Glcp residues and terminated with Fruf residues. Four sulfated heteropolysaccharide fractions (OJP-1, OJP-2, OJP-3 and OJP-4) were isolated and purified from the tuber of *Ophiopogon japonicus* (Xiong et al. 2011). The content of hexuronic acid and sulfate in the four sulfated heteropolysaccharide fractions were in decreasing order OJP-4> OJP-3> OJP-2> OJP-1 and OJP-1S > OJP-4> OJP-3> OJP-2> OJP-1, respectively. OJP-1, a water-soluble polysaccharide isolated from the roots, was found to compose of Ara, Glc and Gal in a relative molar ratio of 1:16:8 and with average molecular weight of 35.2 kDa (Chen et al. 2011). POJ-U1a polysaccharide with molecular weight of 4.02×10^3 Da isolated from *O. japonicus* was an α-configuration an α-configuration polysaccharide with a highly branched structure and consisted of pyranoside and funanside (Wang et al. 2012c). The backbone of POJ-U1a consisted of 1,6-α-D-glucopyranose and 1,3,6-α-D-glucofuranose in the molar ratio of 7:3, while the branched chains were mainly composed of 1,3-α-D-glucopyranose and 1-α-D-glucopyranose in the molar ratio of 1:3.

A novel mannose-binding lectin (designated OJL) was purified from *O. japonicus* rhizomes (Tian et al. 2008; Zhang et al. 2010b). This novel lectin was a homodimer consisting of approximately 12 kDa subunits linked by non-covalent bonds. The haemagglutination activity was stable in the pH range of 5.0–9.0 and at temperatures below 60 °C. The haemagglutination activity of OJL was inhibited by Man-α(1,3:1,6)-mannotriose, Man-α(1,3)-Man, Man-α(1,6)-Man, Man-α(1,2)-Man, Me α-D-man and D-mannose.

Miscellaneous Phytochemicals

β-sitosterol, stigmasterol and β-sitosterol-β-D-glucoside were isolated from the ether-soluble fraction of the rhizome (Kato et al. 1968). A borneol derivative, calcium bornyl sufate, glycerol and α-humulene were isolated from the tubers (Nakanishi and Kameda 1987). Six allelopathic chemicals were isolated from the methanol extracts of dwarf lilyturf roots: *O*-hydroxybenzoic acid, 4-hydroxy-3-methoxybenzoic acid, 4-hydroxy-3,5-dimethoxy benzoic acid, 3,5-dimethoxy-4-hydroxycinnamic acid, syringaldehyde and ρ-hydroxybenzoic acid (Lin et al. 2003b). Salicylic acid and *p*-hydroxybenzoic acid were isolated from the root methanolic extract (Iqbal et al. 2004).

A *cis*-eudesmane sesquiterpene glycoside, ophiopogonoside A, with the structure 1β, 4β,6β-trihydroxy-*cis*-eudesmane-6-*O*-β-D-glucopyranoside, was isolated from the tubers (Cheng et al. 2004). Two anthraquinones, chrysophenol and emodin; 3 phenolic acids, vanillic acid, *p*-hydroxybenzaldenhyde and *trans*-*p*-coumaric acid; two terpenes, L-borneol- β-D- glucopyranoside and oleanolic acid; and two fatty acids, azelaic acid and *n*-tricosanoic acid were isolated from the tubers (Cheng et al. 2005a). Two cyclodipetides cyclo-(Phe-Tyr) and cyclo-(Leu-Ile), N-(2-(4-hydroxyphenyl) ethyl)-4-hydroxycinnamide and tianshic acid were isolated from the tubers (Cheng et al. 2005b). A phenolic glycoside, ophiopojaponin D, with the structure 3-tetradecyloxy-4-hydroxy-allylbenzene-4-*O*-α-L-rhamnopyranosyl (1→6)-β-D-glucopyranoside was isolated from the tubers together with 3, 4-dihydroxy-allylbenzene-4-*O*-α-L-rhamnopyranosyl (1→6)-β-D-glucopyranoside (2) and L-pyroglutamic acid (Dai and Mei 2005). (*E*)-3-(4-Hydr-oxy-3-methoxybenzylidene)-4-(4-hydroxy-phen-yl)pyrrolidin-2-one was isolated from an ethanol extract of *Ophiopogon japonicus* (Zhou et al. 2008b).

Forty-one fat-soluble components were identified from *O. japonicus*, accounting for 81.72 % of the total fat-soluble components with 46.133 % of fatty acids (Shen et al. 2008). 9,12-octadecadienoic acid, hexadecanoic acid, 6-octadecenoic acid and guaiol were the chief components, and their relative contents were 24.648 %,10.829 %,6.367 % and 6.757 %, respectively.

Other Plant Part Phytochemicals

The glycoside ophioside was isolated from the fruit (Arisawa and Nakaoki 1969). Eleven compounds were isolated from *O. japonicus* flowers and identified as β-sitosterol, diosgenin, daucosterol, ophiopogonin C', dioscin, 7-dihydroxy-6-methyl-3-(4′-hydroxybenzyl) chroman-4-one, luteolin, kaempferol-3-*O*-β-D-glucopyranoside, kaempferol-3-*O*-(6″-tigloyl)-β-D-glucopyranoside, kaempferol-3-*O*-(6″-acetyl)-β-D-glucopyranosides and glucose (Zhu et al. 2011).

Antioxidant Activity

Homoisoflavonoids isolated from *O. japonicus* extracts scavenged hydroxyl radical (·OH) and hydrogen peroxide (H_2O_2) into a certain extent, and their bioactivities should be related with the respective structures (Zhou et al. 2008a). Four sulfated heteropolysaccharide fractions (OJP-1, OJP-2, OJP-3 and OJP-4) isolated from the tubers exhibited antioxidant activity (Xiong et al. 2011). In comparison with OJP-1, other polysaccharides showed stronger 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical and hydroxyl radical scavenging activity. POJ-U1 polysaccharide from *O. japonicus* possessed strong antioxidant activity as shown by its DPPH radical scavenging, hydrogen radical scavenging and superoxide anion scavenging activities (Wang et al. 2012b).

Antidiabetic Activity

Many studies found that *O. japonicus* possessed antidiabetic effects supporting the traditional medicinal use of the plant in treating diabetes mellitus. The water-soluble β-D-fructan (MDG- 1) from *O. japonicus* exhibited antidiabetic effects in the *ob*/*ob* mouse model of type 2 diabetes mellitus (Xu et al. 2011). MDG-1 (300 mg/kg) exerted acute and long-term hypoglycaemic effects on fed blood glucose in *ob*/*ob* mice. However, only a marginal hypoglycaemic effect on fasting blood glucose levels was observed. MDG-1 (300 mg/kg) improved oral glucose tolerance and reduced serum insulin levels and triglyceride content in the liver in *ob*/*ob* mice. Additionally, a reduction in body weight gain and the weight of subcutaneous fat were observed following treatment with MDG-1 (150 mg/kg) compared with the control group. MDG-1 had no significant effects on the total cholesterol and triglyceride levels, food intake and other adipose and organ tissues. The data suggested that MDG-1 exhibited hypoglycaemic activity and reduced insulin resistance. Chen et al. (2011) reported that OJP-1, a water-soluble polysaccharide isolated from the roots, was found to have antidiabetic activity. OJP-1 sig-

nificantly reduced blood glucose level, increased the insulin level and remediated destruction of pancreatic islets in streptozotocin -induced diabetic rats compared with the diabetic control group. The water-soluble β-D-fructan (MDG-1) from *O. japonicus* reduced the hyperglycaemia, hyperinsulinaemia and hyperlipidaemia in the KKAy mice (Wang et al. 2012a). The oral glucose tolerance test (OGTT) and the level of insulin in the serum showed that insulin resistance in KKAy mice was ameliorated after MDG-1 treated. After 8 weeks treatment with 300 mg/kg MDG-1, the content of triglycerides (TG) and low-density lipoprotein cholesterol (LDL-C) in the serum decreased significantly, and high-density lipoprotein cholesterol (HDL-C) content increased notably. The authors stated that MDG-1 could be a promising antidiabetic compound that will be helpful for the treatment of type 2 diabetes mellitus.

Studies found that OJP1OJP1, a polysaccharide isolated from *O. japonicus* roots, possessed potent antioxidant activity and could protect the liver and kidneys from the injurious effects of diabetes (Chen et al. 2013b). OJP1 significantly reduced the MDA (malondialdehyde) concentration and increased the activity of both GPx (glutathione peroxidase) and SOD (superoxide dismutase) in the serum, liver and kidneys of streptozotocin-induced diabetic rats. Moreover, the values of TG (triglyceride), TC (total cholesterol), LDL-C (low-density lipoprotein cholesterol) and HDL-C in diabetic rats were significantly reversed by OJP1 treatment. The mRNA expression of transforming growth factor-β1 (TGF-β1) and connective tissue growth factor (CTGF) in diabetic rats decreased significantly after administration of OJP1. Oligosaccharides extracted from *O. japonicus* vinegar (OOV) by alcoholic and acetic acid fermentation with water extracts from the root exhibited stronger inhibition against α-glucosidase than oligosaccharides extracted from the root (OOJ) without fermentation (Lin et al. 2011a). The hypoglycaemic effect of OOV on alloxan-induced diabetic mice was stronger than that of OOJ. More importantly, the ability of OOV to reduce damage on islets in diabetic mice was stronger than that of OOJ. The data suggested that alcoholic and acetic acid fermentation improved the hypoglycaemic activity of *O. japonicus* oligosaccharides. Wang (2013) reported that intragastric administration of *Ophiopogon* polysaccharide for 14 days could decrease the fasting blood glucose level and serum insulin level and improve APN mRNA in fat tissue and placenta of streptozotocin-induced diabetic rats.

MDG-1, a water-soluble β-D-fructan polysaccharide from *O. japonicus*, could treat type 2 diabetes mellitus (T2DM) experimentally (Zhu et al. 2014). To elucidate the antidiabetic mechanism of MDG-1, a faecal metabonomic study was conducted in female diabetic KKay mice. After 8 weeks of treatment with MDG-1, faeces samples were collected for gas chromatography/time-of-flight mass spectrometry analysis. Consequently, 12 potential biomarkers were identified, including monosugars (D-tagatose, D-lyxose, D-erythrose, xylo-hexos-5-ulose, 2-deoxy-galactose), butanedioic acid, amino acids (phenylalanine, L-lysine, L-methionine, L-aspartic acid) and purine derivatives (7H-purine, 2′-deoxyinosine). They assumed that the monosugars and butanedioic acid were the fermentation products of MDG-1 by intestinal microbes, and MDG-1 actions against diabetes might be accomplished through the absorbable monosugars and butanedioic acid via suppressing intestinal glucose absorption, enhancing liver glycogenesis, inhibiting glycogenolysis and promoting glucagon-like peptide-1 (GLP-1) secretion. Besides, MDG-1 might alleviate diabetes and diabetic nephropathy by reducing 7H-purine and 2′-deoxyinosine.

Anticancer Activity

Two homoisoflavonoids ophiopogonone D and ophiopogonanone G isolated from the roots exhibited cytotoxic activities against Hela and Hep2 cells (Duan et al. 2009). *Ophiopogon japonicus* lectin (OJL), a mannose-binding lectin, was found to markedly inhibit growth of MCF-7 cells by induction of apoptosis via a

caspase-dependent pathway (Liu et al. 2009). There was an association among the haemagglutinating activity, antiproliferative activity and mannose-binding activity. *Ophiopogon japonicus* lectin (OJL) was found to induce murine fibrosarcoma L929 cell apoptosis (Zhang et al. 2010b). The mechanism of lectin-induced apoptosis was a caspase-dependent pathway.

Three new steroidal saponins, (25*R*)-ruscogenin-3-yl α-L-rhamnopyranosyl-(1→2)-[β-D-xylopyranosyl-(1→4)]-β-D-glucopyranoside, diosgenin-3-yl 2-*O*-acetyl-α-L-rhamnopyranosyl-(1→2)-[β-D-xylopyranosyl-(1→4)]-β-D-glucopyranoside and pennogenin-3-yl 2-*O*-acetyl-α-l-rhamnopyranosyl-(1→2)-[β-D-xylopyranosyl-(1→4)]-β-D-glucopyranoside, were isolated from the fibrous roots exhibited weak cytotoxicities against Hela and Hep2 cell lines (Duan et al. 2010a). Homoisoflavanones isolated from the tuberousroots,(3*R*)-2,3-dihydro-7-hydroxy-5-methoxy-3-(4-methoxybenzyl)-6,8-dimethyl-4H-chromen-4-one and (3*R*)-3-(1,3-benzodioxol-5-ylmethyl)-2,3-dihydro-7-hydroxy-5-methoxy-6,8-dimethyl-4H-chromen-4-one, showed weak cytotoxicity against the HepG2 (human hepatoma G2), KB (human oral epidermoid carcinoma) and MCF-7 (human breast adenocarcinoma) cell lines (Wang et al. 2010b). Homoisoflavanone (3*R*)-3-(1,3-benzodioxol-5-ylmethyl)-2,3-dihydro-7-hydroxy-5-methoxy-6-methyl-4*H*-chromen-4-one exhibited weak cytotoxicity against HepG2 and MCF-7, and moderate cytotoxicity against KB cell lines while ophiopogonanone A showed moderate cytotoxicity against HepG2, KB and MCF-7 cell lines. Ophiopogonin B (OP-B), a bioactive component of the root, reduced growth of non-small cell lung cancer (NSCLC) cell lines NCI-H157 and NCI-H460 by cell cycle arrest at the GO/G1 phase and autophagy, and not by induction of apoptosis (Chen et al. 2013a). This was associated with its inhibition of PI3K/Akt/mTOR signalling pathway in both cancer cells. Several homoisoflavonoids exhibited promising in-vitro antiproliferative activities against the human lung tumour A549 cell line with IC_{50} values of 0.84–10.01 μM (Zhou et al. 2013).

DT-13, a saponin from *Ophiopogon japonicus*, inhibited MDA-MB-435 lung cancer cell proliferation, adhesion and migration in-vitro and lung metastasis in nude mice by suppressing vascular endothelial growth factor (VEGF), C-C chemokine receptor type 5 (CCR5) and hypoxia-inducible factor 1α (HIF-1α) expression (Zhao et al. 2014).

Anti-inflammatory Activity

O. japonicus root extract significantly inhibited xylene-induced ear swelling and carrageenan-induced paw oedema in mice when given orally at doses of 25 and 50 mg/kg (Kou et al. 2005a). The extract also markedly suppressed carrageenan-induced pleural leucocyte migration in rats and zymosan A-evoked peritoneal total leucocyte and neutrophil migration in mice, while had no obvious effect on pleural prostaglandin E2 level. Further, its two active compounds ruscogenin and ophiopogonin D dose-dependently reduced phorbol-12-myristate-13-acetate (PMA)-induced adhesion of HL-60 cells to ECV304 cells, with IC_{50} of 42.85 μg/mL, 7.76 nmol/L and 1.38 nmol/L, respectively. However, they showed no inhibitory effect on PMA-induced cyclooxygense-2 (COX-2) mRNA expression in ECV304 cells. Ruscogenin and ophiopogonin D also markedly decreased zymosan A-induced peritoneal leucocyte migration. These results demonstrated that *O. japonicus* root extract possessed notable anti-inflammatory activity and supported its traditional use in the treatment of various diseases associated with inflammation. Separate studies showed that ruscogenin, a major steroidal sapogenin of *O. japonicus* root, significantly suppressed zymosan A-evoked peritoneal total leucocyte migration in mice in a dose-dependent manner, while it had no obvious effect on celiac prostaglandin E_2 content in peritoneal exudant (Huang et al. 2008). Ruscogenin also inhibited TNF-alpha induced over expression of ICAM-1 both at the mRNA and protein levels and suppressed NF-kappaB activation considerably by decreasing NF-kappaB p65 translocation and DNA-binding activity. The findings elucidated the possible molecular mechanism of ruscogenin and Radix *Ophiopogon*

japonicus for the inhibition of endothelial responses to cytokines during inflammatory and vascular disorders.

Tran et al. (2010) reported that homoisoflavonoids isolated from the roots exhibited anti-inflammatory activity in-vitro. They inhibited the release of the inflammatory chemokine eotaxin, stimulated by interleukin IL-4 and the combination of IL-4 and TNF-α in BEAS-2B cells. Li et al. (2012a) found six homoisoflavonoids, ophiopogonanone H, 5,7,4′-trihydroxy-3′-methoxy-6,8-dimethyl homoisoflavanone, methylophiopogonanone B, 5,7,2′-trihydroxy-4′-methoxy-6,8-dimethyl homoisoflavanone, methylophiopogonone A and ophiopogonanone E, isolated from the tuberous roots that exhibited potent inhibitory effects on NO production induced by lipopolysaccharide in the murine microglial cell line BV-2 with IC_{50} values of 20.1, 17.0, 7.8, 5.1, 19.2 and 14.4 μM, respectively.

Cardioprotective Activity

Studies had shown that *O. japonicus* possessed cardioprotective activity supporting its use in traditional medicine in treating cardiovascular disorders.

The saponin monomer 13 of dwarf lilyturf tuber (DT-13) was found to have potent cardioprotective effects (Tao et al. 2005). It dose-dependently reduced L-type calcium currents during hypoxia in adult rat ventricular myocytes.

Radix Ophiopogonis polysaccharide (ROP), a natural graminan-type fructan with weight average molecular weight (M_w) of ~5 kDa (Lin et al. 2005), had been found to be very effective against myocardial ischaemia (Zheng et al. 2007, 2009; Wang et al. 2010a). Ophiopogonis polysaccharide protected isolated Langendorff guinea pig heart from myocardium ischaemia–reperfusion injury (IRI) and from subcutaneous injection of isoprenaline induced acute myocardial ischaemia in rats (Zheng et al. 2007). In further studies, they found that sulfation of the polysaccharide significantly enhanced its antimyocardial ischaemic activity (Zheng et al. 2009). Lin et al. (2009a) found the enhanced permeability and retention effect caused by ischaemia could overcome the negative effect of the reduction of blood flow on the distribution of *O. japonicus* polysaccharide (OJP) from blood into myocardial ischaemic zones and actually help OJP target myocardial ischaemic zones where it could exert its pharmacological effect directly.

Wang et al. (2010a) found that MDG-1, the water-soluble β-D-fructan from *O. japonicus*, protected cardiomyocyte and microvascular endothelial cells (HMEC-1) against oxygen glucose deprivation (OGD)-induced cell death, as well as protected myocardial cells from ischaemia-induced death occurring after coronary artery ligation in rats. Their data indicated that MDG-1 presented remarkable anti-ischaemic activity and protected cardiomyocyte and HMEC-1 cells from ischaemia-induced cell damage by inducing sphingosine 1-phosphate (S1P) and basic fibroblast growth factor (bFGF) cytoprotective and proangiogenic effects via the S1P/bFGF/Akt (protein kinase B)/ERK (extracellular signal-regulated kinase)/eNOS (endothelial nitric oxide synthase) signalling pathway. Ophiopogonin D (OP-D), bioactive component of *O. japonicus* root, prevented H_2O_2-induced injury primary human umbilical vein endothelial cells (HUVECs) (Qian et al. 2010). It inhibited mRNA levels of antioxidant, inflammatory and apoptotic genes in a dose-dependent manner in HUVECs. H_2O_2-induced lipid peroxidation, protein carbonylation, mitochondrial ROS generation and cell apoptosis were reduced by OP-D pretreatment. Further, OP-D restored cellular total antioxidative capacity and inhibited the release of inflammatory cytokines. Additionally, OP-D suppressed the enzymatic activity of catalase, HO-1 and caspases. Finally, OP-D blocked activation of NF-κB and ERK signalling cascades. The results indicated that ophiopogonin D could be developed as a novel drug for the therapy of cardiovascular disorders. *Ophiopogon japonicus*, water-soluble β-D-fructan polysaccharide (MDG-1), augments survival in the ischaemic heart by inducing S1P release and sphingosine 1-phosphate receptor 1 ($S1P_1$) expression by activation of the sphingosine kinase enzyme activity coupled with the autocrine and paracrine

stimulation of cell surface S1P receptors (Wang et al. 2012b). Oral administration of oligosaccharides of *Ophiopogonis japonicus* (OOJ) in doses of 225 and 450 mg/kg body weight to high-fat diet and low-dose streptozotocin-induced type 2 diabetic rats for 3 weeks increased body weight decreased organ-related weights of liver and kidney, reduced fasting blood glucose level and improved oral glucose tolerance in diabetic rats (Li et al. 2012b). Studies found that two spirostan compounds 4 and 8 from *O. japonicus* significantly improved on tube formation in human myocardial microvascular endothelial cells, and ophioside A showed moderate increasing effect, while spirostan compound 5 exhibited potent inhibitory effect (Lan et al. 2013).

Studies showed that Shengmai (herbal preparation of ginseng and *Ophiopogon* root) had protective effects on cardiogenic shock (Ding et al. 2007). In the dogs treated with Shengmai, the mean arterial pressure, heart rate, left ventricular pressure, the maximum of its first derivative (+/− dp/dtmax), the cardiac output and the cardiac index were increased significantly. The left ventricular end diastolic pressure and the peripheral vascular resistance were decreased significantly; the myocardial infarct size was reduced markedly. Additionally, the activity of lactate dehydrogenase and creatine kinase and level of malondialdehyde in serum were decreased significantly; however, the activity of superoxide dismutase was increased markedly.

Neuritogenic Activity

Several steroidal saponins and a saponin, isolated from *O. japonicus*, were found to be potent inducers of neuritogenesis on PC12 cells (Qu et al. 2011; Ye et al. 2013). In both studies, the aglycone was found to be more important for the neuritogenic activity of the compounds rather than the sugar moieties and acylation. Also, specific inhibitor experiments and Western blot analysis suggested that the steroidal saponin-induced neuritogenic activity depended on the activation of mitogen-activated protein kinase (MEK)/extracellular signal-regulated kinase (ERK) signalling pathway on PC12 cells (Ye et al. 2013). Compounds with neuritogenic activity could be important in the treatment of neurodegenerative diseases.

Neuroprotective Activity

Shengmai (containing active principles of ginseng and *Ophiopogon* root) injection increased mRNA expression of hypoxia-inducible factor 1-alpha (HIF-1alpha) in neonatal SD rat brain and reduced the apoptosis of hippocampus neurons after hypoxic–ischaemic brain damage (Wang et al. 2009). Guan et al. (2013) found that pretreatment of adult male mice (C57BL/6 strain) with ruscogenin, a major steroid sapogenin from *O. japonicus*, before transient middle cerebral artery occlusion (MCAO)/reperfusion, markedly decreased the infarct size, improved neurological deficits and reduced brain water content after MCAO. NF-κB DNA-binding activity and the expression of NF-κB target genes, including ICAM-1, inducible nitric oxide synthase (iNOS), cyclooxygenase (COX-2), tumour necrosis factor-α (TNF-α) and interleukin-1β (IL-1β), were also suppressed by ruscogenin pretreatment after 1-hour MCAO and 24-hours reperfusion. The results indicated that ruscogenin protected the brain against ischaemic damage caused by MCAO, and this effect may be through down-regulation of NF-κB-mediated inflammatory responses.

Intravenous injection of Shengmai (*Panax ginseng*, *Ophiopogon japonicus* and *Schisandra chinensis*) ameliorated the adverse effects of glomerulosclerosis induced by Adriamycin in SD rats (Peng et al. 1999). Rats treated with Shengmai had lower levels of BUN (blood urea nitrogen), cholesterol and protein urine; also 1 V collagen and laminin content in the renal cortex and mesangial area were reduced significantly compared to glomerulosclerosis rats.

Anti-ageing Activity

Nolinospiroside F, a steroidal saponin, isolated from *O. japonicus* was found to significantly

extend the replicative lifespan of K6001 yeast at doses of 1, 3 and 10 μM, indicating that it had an anti-ageing effect (Sun et al. 2013). This may be attributed to its antioxidative effect, as nolinospiroside F could increase yeast survival under oxidative stress conditions and decrease the level of malondialdehyde (MDA), an oxidative stress biomarker. It could also increase antioxidative stress genes, *SOD1* and *SOD2*, expression and the activity of superoxide dismutase (SOD). It increased the activity of SIRT1, an upstream inducer of *SOD2* expression. Further, nolinospiroside F inhibited the expression of *UTH1*, a yeast-ageing gene involved in the oxidative stress of yeast.

Immunomodulatory Activity

Studies showed that the aqueous extract *Ophiopogon japonicus* could increase obviously the spleen weight (immunity organ) of mice, enhance the clearance rate of i.v. charcoal particles in mice and antagonise markedly the leukopenia caused by cyclophosphamide (Yu et al. 1991).

A fructan, Opaw-2, isolated from the roots, significantly stimulated the proliferation of cultured lymphocytes in a dose-dependent manner (Wu et al. 2006). Four sulfated heteropolysaccharide fractions (OJP-1, OJP-2, OJP-3 and OJP-4) isolated from the tubers exhibited immunomodulatory activity (Xiong et al. 2011). They and OJP-1S exhibited remarkable macrophage-activating capability by the promotion of phagocytic capacity, energy metabolism rate, NO and interleukin-1 production. It was significantly different between five polysaccharides and decreased in the order OJP-1S > OJP-4> OJP-3> OJP-2> OJP-1. Studies showed that sulfated *Ophiopogon* polysaccharide could significantly promote lymphocyte proliferation and enhance serum antibody titre in chicken vaccinated with Newcastle disease vaccine (Zhang et al. 2013). The action was significantly or numerically stronger than those of corresponding unmodified polysaccharides. The results indicated that sulfation modification could enhance the immune-enhancing activity of *Ophiopogon* polysaccharides.

Antithrombotic Activity

In-vivo studies showed that once oral administration of ethanol extract of *O. japonicus* root at doses of 12.5 and 25 mg/kg significantly inhibited venous thrombosis induced by tight ligation of the inferior vena cava for 6 hours in mice and for 24 hours in rats (Kou et al. 2005b). This was associated with its endothelial cell-protective and anti-adhesive activities. This afforded scientific support to the therapeutic use of the plant for thrombotic disease. In further studies, they showed that aqueous extract of Radix *Ophiopogon japonicus* (ROJ-ext) markedly decreased length of tail thrombus in mice at 48 and 72 hours after carrageenan injection at doses of 12.5 and 25.0 mg/kg (Kou et al. 2006). Also, ROJ-ext markedly inhibited thrombosis induced by arterial-venous (AV) shunt (silk thread) in rats at doses of 6.25 and 12.5 mg/kg. Further, ROJ-ext and one of its components, ruscogenin, significantly inhibited platelet aggregation induced by adenosine diphosphate (ADP) in rats by oral administration of 12.5 mg/kg or 0.7 mg/kg for three times; however, ophiopogonin D 1.4 mg/kg only showed slight inhibition. In contrast, ophiopogonin D (0.5–2.0 mg/kg, p.o.) and ruscogenin (0.25–1.00 mg/kg, p.o.) produced dose-related inhibition of venous thrombosis induced by tight ligation of the inferior vena cava for 6 hours in mice by once oral administration.

Cognitive-Enhancing Activity

Ophiopogon japonicus extract ameliorated MK-801-induced amnesia in rats in the avoidance task (Lin et al. 2003c). The extract at 0.1 and 0.3 g/kg prolonged the step-through latency (STL) of the retention trial and reversed the STL shortened by MK-801. The results suggested that the extract possessed cognition-enhancing activities and anti-amnesic effects.

Antihyperlipidaemic Activity

A furostanol glycoside, named ophiopogonin J, isolated from the fibrous root, was found to have fatty acid synthase inhibitory activity (Duan et al. 2012).

Results of studies showed that rats fed with Shengmai San (herbal preparation of *Panax ginseng*, *Schisandra chinensis* and *Ophiopogon japonicus* (2:1:2)) (SMS)-containing diet had reduced the H_2O_2-induced erythrocytes susceptibility to haemolysis, and 4 % SMS feeding rats had higher plasma glutathione concentration compared to the animals fed with high-cholesterol control diet (Yao et al. 2008). However, SMS had no effect on plasma lipids (total cholesterol, triglyceride and high-density lipoprotein cholesterol) and TBARS (thiobarbituric acid reactive substances) concentration. In contrast, rats fed with the 4 % SMS diet had reduced hepatic cholesterol and triglyceride contents. Faecal bile acid excretion was significantly increased in rats fed with the SMS-containing diet. Higher hepatic glutathione and lower TBARS concentrations were observed in rats fed with the 4 % SMS diet compared with the rats fed with the high-cholesterol control diet. No significant difference in activities of glutathione peroxidase, glutathione-S-transferase and superoxide dismutase was found in the liver and heart after the SMS treatment. Results from the study suggested that the SMS may reduce hepatic lipids and lipid peroxidation in rats.

Anti-arrhythmic Activity

The arrhythmias induced by chloroform-epinephrine, BaCl2 and aconitine were prevented and antagonised by *Ophiopogon japonicus* root total saponins (OTS) (Chen et al. 1990). The incidence of ventricular arrhythmia produced by ligation of the left anterior descending coronary artery was effectively decreased without any changes in the haemodynamic indices of dogs. OTS shortened action potential duration APD10, APD50 and APD90 decreased amplitude (APA) and maximum rate of depolarisation (Vmax) x of both monophasic and transmembrane action potentials. OTS also increased the effective refractory period (ERP)/APD ratio and prevented or abolished the arrhythmikinesis provoked by ouabain and aconitine.

Anti-allergic Activity

(Wang et al. 2007) found that immunisation of C57BL/6 mouse with submandibular gland (SMG) autoantigen decreased salivary flow and body weight and increased water intake, SMG index, spleen index, IFN-γ level and IFN-γ/IL-4 ratio compared with the normal group (Wang et al. 2007). Administration of *Ophiopogon japonicus* polysaccharides at the high dose ameliorated these parameters the pathological changes of SMG with respect to the autoallergic model mice. The results suggested a basis for the use of *O. japonicus* in Sjogren's syndrome, an autoimmune disorder characterised by lymphocytic infiltration of salivary and lacrimal glands leading to xerostomia and keratoconjunctivitis sicca.

Antimicrobial Activity

25*S*-ruscogenin and a mixture of ruscogenin and 25S-ruscogenin from the tubers showed antimicrobial activities in-vitro against Gram-positive bacteria, namely, *Bacillus subtilis*, *Staphylococcus aureus*, *Sarcina lutea*, *Streptococcus faecalis* and *Micrococcus lysodeikticus* (Nakanishi and Kameda 1987). A mannose-binding lectin (designated OJL) purified from *O. japonicus* rhizome inhibited herpes simplex virus type II (HSV-II) with an EC_{50} of 3.93 μg/mL and showed antifungal activity against *Gibberella saubinetii* and *Rhizoctonia solani* (Tian et al. 2008).

Skin-Lightening Activity

Methylophiopogonanone B (5,7-dihydroxy-6,8-dimethyl-3-(4-methoxybenzyl)chroman-4-one) had been reported to activate Rho, inducing cytoskeleton disorganisation, and to reduce melanosome transfer by determining a reversible dendrite retraction (Ito et al. 2006). The compound did not influence melanin synthesis or the expression of

melanogenic enzymes and could be considered as a promising skin-lightening compound.

Mucociliary Transport-Enhancing Activity

Studies showed that treatment with *O. japonicus* root (OR) extract was found to have beneficial effects on mucociliary transport following injury to the palate induced by sodium metabisulphite (MB) which releases SO_2 on contact with water (O'Brien et al. 2004). The loss of cilia or ciliated cells prevented full recovery of mucociliary clearance time after MB in untreated bull frog palates. In OR-incubated palates, mucociliary transport was completely restored within 20 minutes after topical application of MB, possibly through a protective action on the extracellular matrix.

Herbal Drug–Drug Interaction Activity

Twenty-two traditional Chinese medicines (TCMs) ethanol extracts including that of *O. japonicus* and eight bioactive compounds could activate pregnane X receptor (PXR) signalling pathway and induce CYP3A4 reporter gene in HepG2 cells (Yu et al. 2011). Therefore, caution should be taken when these PXR activators are used in combination with prescribed drugs metabolised by CYP3A4.

Xia et al. (2009) demonstrated that Shengmai (herbal preparation of ginseng and *Ophiopogon* root) injection could significantly inhibit midazolam 4-hydroxylation but activated its 1′-hydroxylation in human liver microsomes (HLMs), rat liver microsomes (RLM) and recombinant human CYP3A4 and CYP3A5. Among the major components in Shengmai, total ginsenoside, *Ophiopogon* total saponins, *Ophiopogon* total flavone, ginsenoside Rd, ophiopogonin D and ophiopogonone A exhibited significant inhibition on both 4-hydroxylation and 1′-hydroxylation of midazolam in HLM and RLM, while no activation on midazolam metabolism was observed in the presence of these major constituents alone or together.

Pharmacokinetic Studies

Studies showed that oral administration of ophiopogonin saponin D' could be metabolised by intestinal bacteria in the intestine of rat, and its metabolite, diosgenin, was absorbed in blood of rat (Shen et al. 2005). The clearance of FOJ-5, a graminan-type fructan polysaccharide of *O. japonicus* from the bodies of rats following intravenous injection displayed a complex type of kinetics involving at least two compartments, and the half-life of the elimination of FOJ-5 from plasma administered at 15 mg/kg (18.1 minutes) was quicker than that administered at 50 mg/kg (28.9 minutes) (Lin et al. 2005). Lin et al. (2006) found that the sodium caprate containing formulations could significantly improve fluorescein isothiocyanate (FITC)- *O. japonicus* polysaccharide (OJP) bioavailability in rats . Compared with the formulations not containing sodium caprate, the increase varied from 5.6- to 20.8-fold for the worst and best sodium caprate containing formulations studied, respectively. The absorption enhancement effects were 2.1- to 3.6-fold higher than those of faster and slower release formulations studied. In further studies, they found that *Ophiopogon japonicus* polysaccharides (OJP) alone was poorly absorbed from all the rat intestinal segments but was rapidly absorbed when co-administered with sodium caprate (Lin et al. 2009b). The absorption increase was significant, and the best absorption enhancing site of sodium caprate for OJP was the colon.

Radix Ophiopogonis polysaccharide (ROP) had been found to have an excellent antimyocardial ischaemic activity; however, its rapid renal excretion following administration remarkably limits its efficacy and clinical use (Lin et al. 2010a, 2011b). They demonstrated that PEGylation using a moderate coupling reaction between the hydroxyl-activated ROP and the amino-terminated mPEG to prepare different mPEG-ROP conjugates to be a promising approach for improving the clinical efficacy of

ROP by prolonged retention in plasma. The conjugates were found to be well absorbed after subcutaneous administration, with absolute bioavailability being 75.4 % and 43.9 %, respectively (Lin et al. 2011b). Wang et al. (2011b) found that the half-life of PEGylated ROP conjugate following subcutaneous (sc) administration was basically identical to that after intravenous (i.v.) administration. The absolute bioavailability of the conjugate following sc administration was approximately 56 %, and the mean in-vivo residence time was 52.1 hours, increased 2.4 times compared to those of i.v. administration. A simple HPGPC-FD (high-performance gel permeation chromatography–fluorescence detection) method was developed for the sensitive and specific determination of FITC-ROP (fluorescein isothiocyanate-labelled ROP) in plasma and rat tissues (heart, liver, spleen, lung, kidney, brain and stomach) (Lin et al. 2010b). PEGylation was found to be a promising approach to improve the antimyocardial ischaemic activity of Radix Ophiopogonis polysaccharide (ROP) by prolonging its retention in plasma (Lin et al. 2011a). Using a long-circulating and bioactive PEGylated ROP with 1.04 mol 20-kDa mPEG per mol ROP ((1.04)P(20 k)-R), they found that the AUC of (1.04)P(20 k)-R in ischaemic hearts was approximately 1.6-fold greater than in normal hearts owing to enhanced permeability and retention effect caused by ischaemia. Compared with ROP in rats, the distribution tendency of (1.04)P(20 k)-R in the mouse kidney, brain and lung was reduced by approximately 42, 1.6 and 1.3 times, respectively, whereas it was increased by approximately 1.3-fold in the liver.

Toxicity Studies

Toxicity studies demonstrated that Radix Ophiopogonis decoction (26.9 g/kg) had no detectable adverse effects in either the treated F0 female SD rats or the foetuses (Zhang et al. 2010a). No deaths, premature deliveries or dose-related clinical signs were attributed to Radix Ophiopogonis decoction. Maternal body weight and body weight gain were not affected. There were no effects on foetus weight and viability, incidences of foetal malformation and variation.

Traditional Medicinal Uses

Mai men dong is the cardinal herb for Yin deficiency. According to the Chinese Herbal Medicine Materia Medica, the herb is sweet, slightly bitter and slightly cold; enters the heart, lung and stomach; channels and nourishes the yin of the stomach, spleen, heart and lungs; and clears heat and quiets irritability (Bensky et al. 2004). The tuber is antitussive, aphrodisiac, expectorant, pectoral, sedative, sialogogue, stomachic, mucolytic, emollient, demulcent, anti-pyretic, anti-angina, anti-inflammatory, diuretic, cardiotonic, antibacterial, haemostatic, laxative calming, antiscrofulatic and tonic (Yeung 1985; Duke and Ayensu 1985; Bown 1995). It is said to have anticancer activity. *Ophiopogon japonicus* is a traditional Chinese medicine used to treat diabetes for thousands of years (Xu et al. 2011; Zhu et al. 2014) and a traditional Chinese medicine used to treat cardiovascular disease (Wang et al. 2010a). Shengmai San (SMS), which is comprised of the medicinal herbs of *Panax ginseng* root, *Schisandra chinensis* fruit and *Ophiopogon japonicus* root (2:1:2), is a traditional Chinese medicine being used for treatment of coronary heart disease (Yao et al. 2008). Shengmai injection (SMI), one of the most popular herbal preparations, is widely used for the treatment of coronary atherosclerotic cardiopathy and viral myocarditis (Xia et al. 2009). It has been used to relieve coughing, phlegm and heat in the lungs caused by bacterial infection (Liang et al. 2012). It is used internally in the treatment of dry coughs, fevers, thirst, dry constipation, insomnia, anxiety, fearfulness and palpitations (Bown 1995). It is also frequently used to lower blood pressure (Yeung 1985).

Other Uses

In many countries, it is used as ornamental for borders and lawns. Several cultivars have been selected, including “Albus” (white flowers), “Compactus” and “Kyoto Dwarf” (dwarf forms,

not over 4–5 cm tall) and "Silver Dragon" (variegated, with white-striped leaves). It is often sold as a decorative plant for freshwater aquaria, but does not last long in water. It forms a good carpeting plant, spreading rapidly and is commonly planted as a ground cover or as a low-maintenance grass substitute. It is particularly valuable for preventing soil erosion.

The methanolic extract of *O. japonicus* roots exhibited allelopathic activity; it strongly inhibited root and hypocotyls growth of lettuce (Iqbal et al. 2004). Allelopathic constituents of the diethyl ether extract were isolated and identified as salicylic acid and *p*-hydroxybenzoic acid. Among the pair, salicylic acid was found to be the most active one. Six allelopathic chemicals were isolated from the methanol extracts of dwarf lilyturf tuberous roots: *O*-hydroxybenzoic acid, 4-hydroxy-3-methoxybenzoic acid, 4-hydroxy-3,5-dimethoxy benzoic acid, 3,5-dimethoxy-4-hydroxycinnamic acid, syringaldehyde and ρ-hydroxybenzoic acid (Lin et al. 2003b). Dwarf lilyturf has been known to be both a cover crop with weed suppression for gardening in Japan and a medicinal plant (Lin et al. 2003a). They found that all aqueous extracts (1 %, 2 %, 4 %, 8 %, w/v) from the dried powders of underground parts of *Ophiopogon japonicus* inhibited the germination and seedling growth for three weed species, viz. monochoria (*Monochoria vaginalis*), smallflower umbrella (*Cyperus difformis*) and bur-Marigold (*Bidens biternata*). In addition, application of dwarf lilyturf dried powders (50, 100, 150 g/m^2) significantly inhibited emergence and dry weights of weeds existed in paddy field, and had no adverse effects on growth of transplanted rice. From these results, the dwarf lilyturf plants might be used as a natural herbicide to control weeds in rice fields.

The results of studies suggested that the dwarf lilyturf plants have inhibitory potential and could use as a biological fungicide to control rice blast (Lin et al. 2003b). The methanol extract of dried powdered roots inhibited growth of *Pyricularia grisea* in-vitro. Methanol extract of dwarf lilyturf roots significantly inhibited the in-vitro mycelial growth rate of three plant pathogens, *Thanatephorus cucumeris*, *Taphrina deformans* and *Fusarium solani* (Lin et al. 2009a).

Comments

The plant is readily propagated either through seeds or by division of the existing plant.

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Arctium lappa

Scientific Name

***Arctium lappa* L.**

Synonyms

Arctium adhaereus Gilib., *Arctium chaorum* Klokov, *Arctium edule* Beger, *Arctium edule* (Sieb. ex Miq.) Wilp., *Arctium intermedium* Bab., *Arctium lappa* var. *edule* (Sieb. ex Miq.) Mansf., *Arctium lappa* subsp. *majus* Arènes, *Arctium leiospermum* Juz. et al., *Arctium majus* (Gaertn.) Bernh., *Arctium ruderale* Salisb., *Lappa amplissima* Kotschy, *Lappa arctium* Hill, *Lappa bardana* Moench, *Lappa communis* Coss. & Germ., *Lappa communis* var. *major* Neilr., *Lappa edulis* Sieb. ex Miq., *Lappa edulis* Siebold ex Miq., nom. inval., *Lappa glabra* Lam., *Lappa kotschyi* Boiss., *Lappa major* Gaertn., *Lappa officinalis* All., *Lappa vulgaris* Hill.

Family

Asteraceae

Common/English Names

Bat Weed, Beggar's Button, Beggar's Buttons, Burdock, Burs, Clotbur, Cocklebur, Cockle-Button, Cuckold, Edible Burdock, Fox's Clot, Gobo, Grass Burdock, Great Burdock, Greater Burdock, Gypsy Rhubarb, Happy Major, Hardock, Harlock, Harebur, Hurrbur, Lappa, Lesser Burdock, Love Leaves, Personata, Stick Button, Thorny Burr

Vernacular Names

Belarusian: Lopush Vjaliky
Brazil: Bardana, Bardana-Maior, Orelha-Gigante, Pegamaço (Portuguese)
Chenchen: Mashahwieqorg
Chinese: Niu Bang Zi, Niu Pang, Dong Yang Luo Bo, Ngao Pong, Niu Bang
Czech: Lopuch Větší
Danish: Glat Burre, Burre, Læge Burre, Japansk Burre
Dutch: Dokke, Grote Klis, Grote Klit, Dokke, Kladden, Klevers, Jan-Plak-An
Finnish: Iso Takiainen
French: Bardane, Bardane Géante, Bardane Comestible, Bardane Commune, Artichaut, Bardane, Bardane Comestible, Glouteron, Gouteron, Grande Bardane, Grateau, Grateron, Herbe Aux Pouilleux, Herbe Aux Teigneux, Oreille De Géant, Pignet, Teigneux
Gaelic: Leadán
German: Grosse Klette, Bolstern, Filzklette, Haarballe, Haarwachswürze, Kinzel, Kirmsen, Kladde, Klebern, Klette, Klibe, Klibusch, Klitzebusch, Klusen, Wolfskraut, Eßbare Klettenwurzel, Japanische Klettenwurzel

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Greek: Lappa
Hungarian: Bojtorján, Keseru Lapu, Keserulapu Bojtorján, Közönséges Bojtorján
Icelandic: Króklappa
India: Pichawag (Lahaul)
Indonesian: Gobo
Italian: Bardana, Bardana Maggiore, Rfariaccio, Lappa Bardana, Lappola, Lappola Bardana
Japanese: Gobo (Root), Goboshi, Akujitsu, Dairikishi (Fruit)
Korean: Ueong, Uang
Norwegian: Storborre, Klengjegras, Klåteblom, Lungegras
Polish: Lopian, Lopian Wiekszy, Łopian Wiekszy
Portuguese: Bardana-Maior, Erva Dos Tinhosos, Pergamasso, Carrapicho Grande
Spanish: Bardana Mayor, Lampazo, Bardana, Lampazo Mayor, Lapa
Swedish: Kardborrerot, Stor Kardborre, Rodkardborre, Rotkardborre
Vietnamese: Ngu Bang

Origin/Distribution

Burdock is reported to be native to northern Europe to northeast Asia including northern India. It has become naturalised in many parts of the world, growing wild throughout Europe and North America where it is used as folk medicine. The Japanese developed it as an edible vegetable when it was introduced into Japan a thousand years ago. Today, burdock is widely cultivated in Japan, Taiwan and China and also some Southeast Asian countries (in the highlands) mainly for export to Japan.

Agroecology

Burdock is a cool climate, temperate crop flourishing best at temperatures of 18–28 °C in full sun and is frost sensitive. For quality burdock roots, deep profiled and well-drained sandy loam or fresh, worked soil and well-drained soil rich in humus or nitrogen are preferred. Burdock is responsive to nitrogen fertilisers.

Edible Plant Parts and Uses

Burdock root is eaten raw or cooked in a variety of food preparations, and petiole, young leaves and sprouts are also eaten.

The root is very crisp and has a sweet, mild and pungent flavour. It is popularly used in the following Japanese cuisine: burdock in combination with pork in miso soup (*Tinjiro*, *tonjiru*); Japanese-style pilaf (*Takikomi gohan*); *Kinpira gobo* which comprises shredded burdock root and carrot, braised with soy sauce, sugar, mirin and/or sake and sesame oil; and burdock *Makizushi* (sushi filled with pickled burdock root rather than fish; the burdock root is often artificially coloured orange to resemble a carrot). In Kyoto, gobo is also processed as snack similar to potato chips, and the roots are eaten cooked and the young sprouts can be eaten just like bean sprouts.

Botany

A biennial herb growing to 100–300 cm high (Plate 1) with slender, fleshy, tapering roots, which can grow up to 120 cm long and 3–4 cm across. Roots usually have a brown skin with white flesh that oxidises (discolours) quickly when exposed to air. Leaves with 15–35 cm solid, glabrous green or red petioles (Plate 3a, b). Lamina – large, 25–80 × 20–70 cm, coarsely dentate to subentire, cordate, lower surface thinly

Plate 1 Young burdock plant

grey tomentose, upper green, sparsely short hairy to nearly glabrous. Inflorescence heads usually in long-pedunculate corymbiform clusters (Plate 2). Involucres 25–45 mm diameter. Phyllaries linear to linear–lanceolate, glabrous, margins with minute spreading or reflexed hairs. Florets more than 40 with purple, glabrous corollas 10–15 mm. Cypselae light brown, 6.2–7.5 mm and with short pappus bristles 2–5 mm.

Nutritive/Medicinal Properties

Root Nutrients/Phytochemicals

Analyses carried out in the United States reported raw burdock root to have the following proximate composition (per 100 g edible portion): water 80.09 g; energy 72 kcal (302 kj); protein 1.53; total lipid 0.15 g; ash 0.89 g; carbohydrates 17.34 g; total dietary fibre 3.3 g; total sugars 2.90 g; Ca 41 mg, Fe 0.8 mg, Mg 38 mg, P 51 mg, K 308 mg, Na 5 mg, Zn 0.33 mg, Cu 0.077 mg, Mn 0.232 mg, Se 0.7 µg, vitamin C 3.0 mg, thiamine 0.010 mg, riboflavin 0.030 mg, niacin 0.300 mg, pantothenic acid 0.321 mg, vitamin B6 0.240 mg, total folate 23 µg, choline 11.7 mg, betaine 0.2 mg, vitamin A 0 IU, vitamin E (α-tocopherol) 0.30 mg and vitamin K (phylloquinone) 1.6 mcg; total saturated fatty acids 0.025 g and 16:0 (palmitic acid) 0.025 g; total monounsaturated fatty acids 0.037 g and 18:1 undifferentiated (oleic acid) 0.037 g; total polyunsaturated fatty acids 0.059 g, 18:2 undifferentiated (linoleic acid) 0.056 g and 18:3 undifferentiated (linolenic acid) 0.002 g; and tryptophan 0.006 g, threonine 0.026 g, isoleucine 0.030 g, leucine 0.032 g, lysine 0.067 g, methionine 0.009 g, cystine 0.006 g, phenylalanine 0.033 g, tyrosine 0.018 g, valine 0.033 g, arginine 0.105 g, histidine 0.031 g, alanine 0.025 g, aspartic acid 0.177 g, glutamic acid 0.157 g, glycine 0.031 g, proline 0.052 g and serine 0.025 g (USDA-ARS 2014). Dry burdock root extract contained (mg/g) 0.011 mg Cu, 0.5520 mg Na, 7.47 mg K, 0.0035 mg Mn, 0.0239 mg Pb, 0.0270 mg Fe, 0.391 mg Mg and 0.0128 mg Cd and 12.1 % protein and 15 amino acids (wt%), namely,

Plate 2 Burdock inflorescences and leaves

Plate 3 (**a**, **b**) Burdock root, whole and halved

asparagine 2.5 %, threonine 0.8 %, serine 1.1 %, glutamine 6.7 %, proline 0.9 %, glycine 1 %, alanine 1 %, valine 1 %, isoleucine 0.8 %, leucine 1.6 %, tyrosine 0.8 %, phenylalanine 1.2 %, histidine 0.7 %, lysine 0.9 % and arginine 2.5 % (Azizov et al. 2012). The dry extract of burdock roots contained 40.5 % inulin; mineral elements (mg/g), Cu 0.0112 mg, Na 0.55 mg, K 7.47 mg, Mn 0.0035 mg, Pb 0.0239 mg, Cd 0.0128 mg, Fe 0.027 mg and Mg 0.391 mg (Azizov et al. 2012); and 12.1 % protein comprising asparagines 2.5 %, threonine 0.8 %, serine 1.1 %, glutamine 6.7 %, proline 0.9 %, glycine 1 %, alanine 1 %, valine 1 %, isoleucine 0.8 %, leucine 1.6 %, tyrosine 0.8 %, phenylalanine 1.2 %, histidine 0.7 %, lysine 0.9 % and arginine 2.5 %. Khamidova et al. (2009) reported burdock to contain up to 45 % of the polysaccharide inulin, 12.3 % protein, up to 0.2 % essential oil, up to 3.9 % fatty oil, organic acids, 13.2 % carotenoids, 0.7 % flavonoids and tanning agents and bitter principles. Yamada et al. (1975) isolated γ-guanidino-*n*-butyric acid from burdock root. Kuo et al. (2012) identified α-linolenic acid, methyl α-linolenate and methyl oleate in the n-hexane fraction of burdock root.

From burdock roots the following compounds were isolated: sulfur-containing acetylenic acid named arctic acid with the structure 5′-(1-propynyl)-5-carbomethoxy-2, 2′-bithienyl; volatile acids, acetic, propionic, *n*-butyric, isobutyric, isovaleric, tiglic and *trans*-2-hexenoic acids; non-hydroxy acids, lauric, myristic, stearic, palmitic, oleic, linoleic and linolenic acids; aldehydes, acetaldehyde, propionaldehyde, butanal isobutyraldehyde, *n*-valeraldehyde, isovaleraldehyde, *n*-caproic aldehyde, *n*-caprylic aldehyde and benzaldehyde; and 2,4-dinitrophenylhydrazones of carbonyl compounds (Obata et al. 1970).

Schulte et al. (1967) identified 14 polyacetylenes in fresh burdock roots of different samples with 1,11-tridecadien-3,5,7,9-tetrayne (up to 1.5 mg%), 1-tridecene-3,5,7,9,11-pentayne (up to 1.1 mg%) and 1,3,11-tridecatriene-5,7,9-triyne (up to 0.2 mg%) as major components. Treatment of sliced burdock root tissue with copper sulfate stimulated the formation of two phytoalexins, isolated and characterised as (S)-12,13-epoxy-2,4,6,8,10-tridecapentayne and 1-tridecene-3,5,7,9,11-pentayne (Takasugi et al. 1987). Burdock also contained baicalin (Uchiyama et al. 2005); lappaphen-a and lappaphen-b, two guaianolides linked with a sulfur-containing acetylenic compound (Washino et al. 1987); polyacetylenic compounds, namely, 1,11(*E*)-tridecadien-3,5,7,9-tetrayne; (3*E*,11*E*)-1,3,11-tridecatriene-5,7,9-triyne; (3*E*)-3-tridecen-5,7,9,11-tetrayn-1,2-epoxide as C_{13} polyynes; (8*Z*,15*Z*)-heptadeca-1,8,15-heptadecatriene-11,13-diyne as C_{17} polyyne; and (4*E*,6*E*,12*E*)-4,6,12-tetradecadien-8,10,12-triyn-1,3-diyl diacetate; (4*E*,6*Z*,12*E*)-4,6,12-tetradecadien-8,10,12-triyn-1,3-diyl diacetate; (4*E*,6*E*)-4,6-tetradecadien-8,10,12-triyn-1,3-diyl diacetate and (4*E*,6*Z*)-4,6-tetra-decadien-8,10,12-triyn-1,3-diyl diacetate (Washino et al. 1986b). Nine sulfur-containing acetylenic compounds and derivatives 5′(1-propynyl)-2,2′-bithienyl-5-yl were isolated and identified as arctinone-a and arctinone-b, arctinol-a and arctinol-b, arctinal, arctic acid-b and arctic acid-c, methyl arctate-b and arctinone-a acetate (Washino et al. 1986a). Arctic acid, arctinone-a, arctinone-b and methyl arctate-b, minor components of *Arctium lappa* were synthesised via 5-(1-propynyl)-2,2′-bithienyl starting from 2,2′-bithienyl (Washino et al. 1986c). From burdock methanol extract, the following compounds were isolated sitosterol-β-D-glucopyranoside, methyl palmitate, methyl linoleate, methyl linoleneate, methyl stearate, methyl oleate, palmitic acid, linoleic acid, linolenic acid, stearic acid and oleic acid (Miyazawa et al. 2005). Seventeen compounds were isolated from burdock root ethanol solution: three from petroleum ether extract (β-sitosterol, oleanolic acid, ursolic acid), four from chloroform extract (β-sitosterol, daucosterol, syringaresinol, ethyl-β-D-pyran fruit glycoside), one from ethyl acetate extract (1,5-di-*O*-caffeoylquinic acid) and two from *n*-butanol extract (succinic acid and 5-hydroxymaltol). Oleanolic acid, ursolic acid, clove lignans, ethyl-β-D-pyran fruit glycoside, succinic acid and 5-hydroxymaltol were also isolated (Han et al. 2013).

The presence of flavonoids, saponins, lignans and alkaloids was reported in burdock (Cao et al. 2012).

A xyloglucan isolated from burdock KOH extract was found to comprise predominantly of repeating oligosaccharide units of hepta-(Glc–Xyl = 4:3), nona-(Glc–Xyl–Gal–Fuc = 4:3:1:1) and deca-(Glc–Xyl–Gal–Fuc = 4:3:2:1) saccharides in an approximate molar ratio of 14:12:5 (Kato and Watanabe 1993). A low molecular weight fructofuranan of the inulin type was isolated from the roots (Kardosová et al. 2003). Burdock root was reported to contain 45 % of the polysaccharide inulin, 12.3 % protein, up to 0.2 % essential oil, up to 3.9 % fatty oil, organic acids, 13.2 % carotenoids, 0.7 % flavonoids and tanning agents and bitter principles (Azizov et al. 2012). Inulin and oligofructose are soluble, fermentable, dietary fibres, of low net caloric value having many of the possible health benefits attributed to fibre (Carabin and Flamm 1999). Such fibre was reported to comprise of polymers and oligomers of fructose joined by β(2→1) fructosyl–fructose bonds. Optimum ultrasound extraction condition for inulin from burdock roots was found to have a sonication time of 25 minutes, sonication amplitude of 83.22 % and temperature of 36.76 °C (Milani et al. 2011). Seven fructooligosaccharides with degrees of polymerisation (DP) between 3 and 9, as well as fructose, glucose and sucrose, were simultaneously determined in burdock from different regions (Li et al. 2013). The recoveries ranged from 99.2 to 102.6 %.

The cell walls of gobo consisted of pectic substances (rhamnogalacturonan with neutral sugars), hemicellulose (arabinan, xylan, galactan, arabinogalactan and xyloglucan) and cellulose in the ratio of 53.6:8 and 0:38.4, respectively (Yato et al. 1991). The approximate ratio of fructan and cell wall polysaccharides was 47:53 for gobo. An acidic xylan with a backbone chain of β-(1→4)-xylopyranosidic residues, about 8.3 % of which were substituted at the 2-position with 4-*O*-ethyl-α-D-glucopyransoyl-uronic acid residues, was isolated from gobo (Watanabe et al. 1991). A xyloglucan was isolated from the 24 % KOH extract of gobo (Kato and Watanabe 1993). It consisted of repeating oligosaccharide units of hepta-(Glc–Xyl=4:3), nona-(Glc–Xyl–Gal–Fuc=4:3:1:1) and deca-(Glc–Xyl–Gal–Fuc=4:3:2:1) saccharides. A fructan–fructan 1-fructosyltransferase (1-FFT) was purified from edible burdock, and a cDNA encoding 1-FFT was isolated from the plant (Abe et al. 2009). Two 1-FFTs named 1-FFTa and 1-FFTb were purified from extract of edible burdock, and FFT cDNA named *alft1* was found to be involved in the elongation of fructosyl chains of fructooligosaccharides in edible burdock. Three fructooligosaccharide derivatives without a terminal glucose residue were generated in burdock roots stored underground from November to May (Ishiguro et al. 2009). They were determined to be inulobiose [β-D-fructofuranosyl-(2→1)-β-D-fructopyranose], inulotriose [β-D-fructofuranosyl-(2→1)-β-D-fructofuranosyl-(2→1)-β-D-fructopyranose] and inulotetraose [β-D-fructofuranosyl-(2→1)-β-D-fructofuranosyl-(2→1)-β-D-fructofuranosyl-(2→1)-β-D-fructopyranose]. Seventy to eighty percent of the terminal fructose residue of the three saccharides was in pyranosyl form, while 20–30 % in furanosyl form. Variation of total FOS, total IOS, inulin and their related-metabolising enzymes, sucrose hydrolase (SH), 1-kestose hydrolase (1-KH), inulin hydrolase (InH), sucrose–sucrose 1-fructosyltransferase (1-SST) and fructan–fructan 1-fructoslytransferase (1-FFT) in burdock stored under different temperatures, was found to be dependent partly on temperature and other physiological factors (Ishiguro et al. 2010a). SH showed an irregular variation at 15 and 20 °C and was significantly higher at 0 °C showing a continuous increase during the storage period. 1-KH decreased progressively at 15 and 20 °C, but had a sharp rise at 0 °C after 2 weeks and decreased thereafter. InH decreased gradually at 0, 15 and 20 °C. However, the decrease was more significant at 15 and 20 °C during the first 2 weeks, while at 0 °C the decrease was significant after 4-week storage. 1-SST and 1-FFT activities decreased progressively and showed similar patterns. At 15 and 20 °C, total FOS increased during the first 3 weeks and then decreased, while at 0 °C FOS increased progressively during storage. Total IOS increased during storage; however, this increase was much higher at 0 °C than that observed at 15 and 20 °C. Inulin content decreased during storage and final content was lower at 20 °C. Further, they found that

low temperature induced strongly the hydrolysis of inulin and formation of IOSs in burdock root suggesting that this reaction would not be the result of a putative endo-inulinase but resulted from the activity of fructan–fructan 1-fructosyltransferase (1-FFT) (Ishiguro et al. 2010b). At 15 and 20 °C, inulobiose appeared after 3-day storage, and then, it increased gradually to 2.03 and 2.72 mg/g dry weight (DW) after 42 days, while inulotriose, inulotetraose, inulopentaose, inulohexaose and inuloheptaose appeared after 1 week and increased also progressively. At 0 °C, the different inulooligosaccharides (IOSs) increased sharply after the second week, but inulobiose and inulotriose decreased slightly after 5 weeks. However, their contents were much higher than those observed at 15 and 20 °C. A water-soluble polysaccharide (ALP1) purified from burdock root was characterised as a fructan composed of fructose and glucose in the ratio of 13.0:1.0, with an average molecular weight of 4,600 Da. The linkages in ALP1 were →1)-Fruf-(2→, Fruf-(2→ and Glcp-(1→ (Liu et al. 2014).

Ferredoxin from *Arctium lappa* was found to consist of a single polypeptide chain of 97 residues, four of which were cysteine (Takruri et al. 1982). Ueno et al. (2011) isolated a gene cDNA, named *aleh1*, encoding for fructan 1-exohydrolase (1-FEH) in edible burdock. *Aleh1* encoded a polypeptide of 581 amino acids. The purified recombinant protein showed hydrolysing activity against β-2, 1 type fructans such as 1-kestose, nystose, fructosylnystose and inulin. In contrast, sucrose, neokestose, 6-kestose and high DP levan were poor substrates.

Five caffeoylquinic acid derivatives were isolated from the roots: 1-*O*-,5-*O*-dicaffeoylquinic acid; 1-*O*-,5-*O*-dicaffeoyl-3-*O*-succinylquinic acid; 1-*O*-,5-*O*-dicaffeoyl-4-*O*-succinylquinic acid; 1-*O*-,5-*O*-dicaffeoyl-3-*O*-,4-*O*-disuccinylquinic acid; and 1-*O*-,3-*O*-, 5-*O*-tricaffeoyl-4-*O*-succinylquinic acid (Maruta et al. 1995). Hydroxycinnamoylquinic acids identified in burdock roots included 1-caffeoylquinic acid, 3-caffeoylquinic acid and 4-caffeoylquinic acid, chlorogenic acid, 1,3-dicaffeoylquinic acid, caffeoylquinic acid glycoside, 3,4-dicaffeoylquinic acid, 1,4-dicaffeoylquinic acid, 3,5-dicaffeoylquinic acid, 1,5-dicaffeoylquinic acid, 4,5-dicaffeoylquinic acid, 1,5-dicaffeoyl-3-succinoylquinic acid, 1,5-dicaffeoyl-4-succinoylquinic acid, 1,3,5-tri-caffeoylquinic acid, 1,5-dicaffeoyl-3,4-disuccinoylquinic acid, 1,3,5-dicaffeoyl-4-succinoylquinic acid and 3,4,5-tricaffeoylquinic acid (Lin and Harnly 2008). Hydroxycinnamoylquinic acids, 5-*O*-caffeoylquinic acid, 1,4-di-*O*-caffeoylquinic acid, 1,5-di-*O*-caffeoylquinic acid and 3,5-di-*O*-caffeoylquinic acid, and 15 quantitatively minor fumaric, succinic and malic acid-containing chlorogenic acids were identified in burdock roots (Jaiswal and Kuhnert 2011). These were 3-*O*-succinoyl-4,5-dicaffeoyl or 1-*O*-succinoyl-3,4-dicaffeoylquinic acid, 1,5-di-*O*-caffeoyl-3-succinoylquinic acid, 1,5-di-*O*-caffeoyl-4-succinoylquinic acid, 3,4-di-*O*-caffeoyl-5-succinoylquinic acid, 1,3-di-*O*-caffeoyl-5-fumaroylquinic acid, 1,5-di-*O*-caffeoyl-4-fumaroylquinic acid, 1,5-di-*O*-caffeoyl-3-maloylquinic acid, 1,4-di-*O*-caffeoyl-3-maloylquinic acid, 1,5-di-*O*-caffeoyl-4-maloylquinic acid, 1,3,5-tri-*O*-caffeoyl-4-succinoylquinic acid, 1,5-di-*O*-caffeoyl-3,4-disuccinoylquinic acid, 1,5-di-*O*-caffeoyl-3-fumaroyl-4-succinoylquinic acid, 1-fumaroyl-3,5-di-*O*-caffeoyl-4-succinoylquinic acid, dicaffeoyl-dimaloylquinic acid and 1,5-di-*O*-caffeoyl-3-succinoyl-4-dimaloylquinic acid. Phenolic compounds found in the hydroethanolic extract of burdock root extracts included artigenin, quercetin, chlorogenic acid and caffeic acid (Predes et al. 2011). Arctiin, luteolin and quercetin rhamnoside were identified in burdock roots (Ferracane et al. 2010). The total phenolic content of burdock roots and leaves ranged from 3.93 to 14.13 g of chlorogenic acid (5-CQA) equivalent/100 g dry weight (DW) (Haghi et al. 2013). There was a significant variability from 89 to 571 mg/100 g for 5-CQA and 48–486 mg/100 g for 11,5-dicaffeoylquinic acid in dry material. Chlorogenic acid, used as a chemical marker for HPTLC analysis, was estimated to be 0.107–0.140 % in *A. lappa* root (Pandey et al. 2004, 2007). The mean values of total contents of biofunctional components (chlorogenic acid, 1-*O*-,5-*O*-dicaffeoylquinic acid and 1-*O*-,5-*O*-dicaffeoyl-3-*O*-succinylquinic acid) in burdock roots varied from 1.7 to 7.9 mg/g dry weight (Wang et al. 2001).

Nine hydrocarbons (cyperene, 1-pentadecene, β-elemene, caryophyllene, clovene, α-guaiene, 1-heptadecene, dihydroaplotaxene and aplotaxene); 19 aldehydes (propanal, 2-methylpropanal, butanal, 3-methylbutanal, pentanal, hexanal, heptanal, (*Z*)-3-hexenal, (*E*)-2-hexenal, octanal, nonanal, (*E*)-2-octanal, decanal, benzaldehyde, undecanal, phenylacetaldehyde, dodecanal, tridecanal and 4-methoxybenzaldehyde); seven 2-alkyl-3-methoxypyrazines,namely,2-methoxy-3-methylpyrazine, 2-isopropyl-3-methyoxylpyrazine, 2-methoxy-3-propylpyrazine, 2-sec-butyl-3-methoxypyrazine, 2-isobutyl-3-methoxypyrazine, 2-butyl-3-methoxypyrazine and 2-isoamyl-3-methoxypyrazine; 32 acids, namely, acetic acid, propionic acid, 2-methylpropionic acid, butyric acid, 2-methylbutyric acid, 23-methylbutyric acid, pentanoic acid, hexanoic acid, (*E*)-3-hexenoic acid, heptanoic acid, (*E*)-3-heptenoic acid, octanoic acid, (*E*)-3-octenoic acid, nonanoic acid, (*E*)-3-nonenoic acid, decanoic acid, benzoic acid, undecanoic acid, phenylacetic acid, salicylic acid, dodecanoic acid, 2-phenylpropionic acid, 3-hydroxyoctanoic acid, cinnamic acid, tridecanoic acid, tetradecanoic acid, 3-methoxybenzoic acid, pentadecanoic acid, nonanedioic acid, hexadecanoic acid, costic acid and octadecanoic acid; and two sesquiterpenoids, dehydrocostus lactone and dehydrodihydrocostus lactone, were isolated and identified in the volatile components of burdock roots (Washino et al. 1985) Aplotaxene, dehydrocostus lactone, dehydrodihydrocostus lactone and costic acid were identified as major components. The volatile oil from burdock roots yielded 14 compounds, representing 85.4 % of the total composition (Aboutabl et al. 2013). The major compound was caryophyllene oxide (51.1 %), followed by aromadendrene (16 %) and isoaromadendrene epoxide (6.4 %). Other components were γ-cadinene 2.79 %, β-costol 1.98 %, β-copaen-4α-ol 1.69 %, hexacosane 1.41 %, α-pinene 0.5 %, eicosane 0.35 %, pentacosane 0.19 %, heptacosane 0.19 %, *trans*-β-farnesene 0.11 %, tetracosane 0.09 % and carvomenthone 0.03 %. Sixty-three compounds were identified representing 87.67 % of the total contents of burdock essential oil (Wang et al. 2004). The major constitutes were methyl linolenate, linoleic acid, 2-naphthalenemethanol, decahydro- and benzaldehyde.

Polyphenol oxidase purified from burdock had a molecular weight of 31,000 estimated by SDS-PAGE and 25,000 by gel filtration (Murao et al. 1993). The enzyme had properties different from those of polyphenol oxidases from other sources such as mandarin orange and soybean. Polyphenol oxidase purified from burdock was estimated to have a molecular weight of about 41,000 and 40,000 by gel filtration and SDS-PAGE, respectively (Han et al. 2006). The purified enzyme quickly oxidised chlorogenic acid and (−)-epicatechin. The optimum pHs were 5.0 for chlorogenic acid oxidase (ChO) and 8.0 for (−)-epicatechin oxidase (EpO).

The weight loss of burdock was as high as 60 % of fresh weight when corrugated cardboard cartons were used for storage at 20 °C (Ishimaru et al. 2004). However, polyethylene bag packaging or low-temperature storage resulted in lower levels of weight loss (less than 30 %). There was a significant decline in sugar content during storage at 8 and 20 °C, corresponding to an increased production of white solids. The fructan composition of raw burdock roots decreased faster to about 60 % after storage for 30 days at 2 °C than at other storage temperatures (to about 30 %). Inulinase activity in burdock roots stored at 2 °C was higher than those stored at 8 and 20 °C. The storage of burdock roots in polyethylene film packaging for 30 days at 2 °C was suitable to prevent the formation of muddy precipitate in processed burdock sticks.

Leaf Phytochemicals

Nutritional composition of burdock leaves was more superior in the leaves than in the petioles (Itabashi and Takamura 1985).

Ten compounds, namely, eremophilene, fukinone, petasitolone, fukinanolide, β-eudesmol, taraxasterol and its esters, acetate and palmitate, including two new sesquiterpenes dehydrofukinone and arctiol, were isolated from burdock leaves (Naya et al. 1972). Dehydrofukinone and arctiol

were confirmed to be $\Delta^{9(10)}$-fukinone and 8α-hydroxyeudesmol, respectively. Burdock leaves contained triterpene alcohols α-amyrin, β-amyrin, lupeol, phytol, taraxasterol and ω-taraxasterol in free and esterified state as well as sterols stigmasterol and sitosterol (Yochkova et al. 1989). A sesquiterpene lactone onopordopicrin was isolated from burdock leaves (Barbosa-Filho et al. 1993). Two sesquiterpene lactones arctiopicrin and onopordopicrin were isolated from the juice of fresh burdock leaves (Savina et al. 2006). Compounds isolated from burdock leaves were onopordopicrin, dehydromelitensin-8-(4′-hydroxymethacrylate), dehydromelitensin, melitensin, dehydrovomifoliol and loliolide (Machado et al. 2012).

Lignans, arctiin and artigenin were isolated from the leaves (Liu et al. 2005a). Phenolic acids, quercetin, quercitrin and luteolin in burdock leaves were reported for the first time (Ferracane et al. 2010). The phenolic compounds identified in various burdock leaf fractions were chlorogenic acid, *o*-hydrobenzoic acid, caffeic acid, *p*-coumaric acid and rutin (Lou et al. 2010a); benzoic acid and *p*-coumaric acid (Lou et al. 2010c). Two triterpenoids, characterised as 3α-hydroxylanosta-5,15-diene and 3α-acetoxyhop-22(29)-ene. 3α-hydroxylanosta-5,15-diene, were isolated from the leaves (Jeelani and Khuroo 2012). High amount of pectic substances about 1.9 % per wet mass (about 21 % of dry mass) was detected in the leaf stems of burdock (Mkrtchian et al. 1998). The uronide component of burdock pectin was 66 %, esterification rate 47 %, methoxyl component 9 %, equivalent weight 343 and free carboxyl group content 16 %.

The volatile constituents from the leaves showed 19 identified compounds, the major being caryophyllene oxide (54.2 %), followed by β-elemene (6.2 %) and β-costol (4.03 %) (Aboutabl et al. 2013). Other components included hexacosane 2.67 %, β-copaen-4α-ol 2.06 %, nonadecane 1.77 %, γ-cadinene 1.70 %, eicosane 1.48 %, pentadecane 1.43 %, tetracosane 1.27 %, tetradecane 0.75 %, nonanal 0.72 %, docosane 0.64 %, α-pinene 0.50 %, heptacosane 0.46 %, limonene 0.23 %, carvomenthone 0.11 %, *trans*-β-farnesene 0.1 % and pentacosane 0.09 %.

The enzyme preparation from burdock petioles catalysed the enantioselective formation of (+)-secoisolariciresinol from coniferyl alcohol in the presence of NADPH and H_2O_2 (Umezawa and Shimada 1996). The (+)-enantiomer of secoisolariciresinol was the predominant antipode of secoisolariciresinol isolated from burdock petioles.

Boldizsár et al. (2010) reported that upon acidic hydrolysis the dibenzylbutyrolactone-type lignans (arctiin, arctigenin, methylarctigenin, matairesinoside, matairesinol) were stable, while the diphenylperhydrofurotetrahydrofurane-type lignans (phylligenin, pinoresinol) decomposed. The fragment species of the derivatised lignan glycosides, in the presence of excess hexamethyldisilazane, led to their in situ derivatisation. The distribution of the lignan constituents was presented for five *Arctium*, for eight *Centaurea* and for four *Forsythia* plant extracts: the total of lignan contents varied between 0.42 and 87.9 mg/g, respectively.

Fruit/Seed Phytochemicals

The following lignans were isolated from burdock seeds: lappaols A and B (Ichihara et al. 1976); lappaols C, D and E (Ichihara et al. 1977); lappaols F and H (Ichihara et al. 1978); and lappaols A and F (Ichihara et al. 1979). Five compounds identified as daucosterol, arctigenin, arctiin, matairesinol and lappaol F and a new lignan named neoarctin were isolated from burdock seeds (Wang and Yang 1993). Neoarctin A (Wang and Yang 1995) and six compounds daucosterol, arctigenin, arctiin, matairesinol, lappaol F including a new lignan named neoarctin B were isolated from burdock seeds (Wang and Yang 1993). Cell-free extracts from ripening seeds of *Arctium lappa* catalysed the enantioselective formation of (−)-pinoresinol, (−)-lariciresinol and (−)-secoisolariciresinol from achiral coniferyl alcohol in the presence of NADPH and H_2O_2 (Suzuki et al. 1998, 1999). The enantioselectivity of the lignan formation was opposite to that of the (+)-secoisolariciresinol formation catalysed by cell-free extracts from petioles of the

same plant species. The petiole enzyme preparation catalysed the formation of (+)-pinoresinol (33 % e.e.), (+)-lariciresinol (30 % e.e.), and (+)-secoisolariciresinol (20 % e.e.) from achiral coniferyl alcohol in the presence of NADPH and H202, whereas that from ripening seeds catalysed the formation of (−)-pinoresinol (22 % e.e.), (−)-lariciresinol (>99 % e.e.) and (−)-secoisolariciresinol (38 % e.e.) under the same conditions (Suzuki et al. 2002). In addition, the ripening seed enzyme preparation mediated the selective formation of the optically pure (>99 % e.e.) (−)-enantiomer of matairesinol from racemic (+/−)-secoisolariciresinols in the presence of NADP.

A novel lignan, diarctigenin, with the structure bis-5′,5′-arctigenin, together with the known butyrolactone derivatives, arctigenin and arctiin, was isolated from burdock seeds (Han et al. 1994). Arctigenin, major burdock lignin, with the systematic name (3R-*trans*)-4-[(3,4-dimethoxyphenyl) methyl]-3-[(4-hydroxy-3-methoxyphenyl) methyl]-4,5-dihydrofuran-2(3H)-one, was found to have dibenzylbutyrolactone skeleton (Gao et al. 2008).

Seven compounds, β-sitosterol, daucosterol, lappaol C, lappaol A, arctignan E, lappaol F and arctiin, were isolated from burdock seed methanol extract (Dong et al. 2004). The occurrence of some phenolic acids (caffeic acid, chlorogenic acid and cynarin) was detected in burdock seeds (Ferracane et al. 2010). A new lignan neoarctin A, together with nine known compounds, matairesinol; arctiin; lappaols A, E, F and H; and arctignans A, G and H, was obtained from the ethanolic extract of burdock seeds (Yong et al. 2007). The contents of arctiin and arctigenin in burdock seed samples were 53.7 and 9.7 mg/g (0.5 and 0.1 %) of dry sample, respectively (Kravtsova and Khasanov 2011). The fatty acid esters determined as normalised per cent of the total of all identified esters were (% GC–MS) 14:0, tr.;16:1, tr.; 16:0, 6.8; 18:0, 3.5; 18:1(9), 26.7; 18:1(12), 1.6; 18:2, 60.3; 20:0, 0.7; 22:0, 0.3; and 24:0, 0.2 %. Linoleic acid (18:2) had the greatest per cent content. Small amounts of myristic (14:0) and palmitoleic (16:1) acids were also observed. 12-Octadecenoic acid (18:1) and the three acids 20:0, 22:0 and 24:0 were detected for the first time in burdock seed.

Three lignan compounds, namely, 3′-demethyl arctigenin, arctigenin and arctigenin glucoside, were isolated from the seed (Kamkaen et al. 2006). A new butyrolactone sesquilignan, isolappaol C, together with two known sesquilignans lappaol C and lappaol D and two known dilignans lappaol F and diarctigenin, was isolated from the methanolic extract of the seeds (Park et al. 2007). Seeds (dry samples) were found to contain mainly arctiin 53.7 mg/g and arctigenin mg/g and also fatty acid esters determined as 14:0 (myristic acid) traces, 16:0 (palmitic acid) 6.8 %, 18:0 (stearic acid) 3.5 %, 16:1 (palmitoleic acid) traces, 18:1 (n9) (9-octadecenoic acid) 26.7 %, 18:1 (n12) (12-octadecenoic acid) 1.6 %, 18: 2 (linoleic acid) 60.3 %, 20:0 (arachidic acid) 0.7 %, 22:0 (behenic acid) 0.3 % and 24:0 (lignoceric acid) 0.2 % (Kravtsova and Khasanov 2011). Phenolic compounds arctigenin; arctiin; chlorogenic acid; 4,5-dicaffeoylquinic acid; 3,5-dicaffeoylquinic acid; 3,4-dicaffeoylquinic acid; matairesinol; isolappaol A; lappaol F; and lappaol B, together with 1:1 mixtures of isolappaol C and lappaol C, arctignan E and arctignan D and isolappaol A and lappaol A, were isolated from burdock seeds, while 3,3′,4′-tri-*O*-demethylarctigenin, 3,3′-di-*O*-demethyl-4′-dehydroxyarctigenin and 3-*O*-demethylarctigenin were obtained by anaerobic microbiological metabolism of arctigenin (Tezuka et al. 2013). A total of 14 lignans were identified in burdock seeds and 12 caffeoylquinic acids in burdock roots (Liu et al. 2012). High levels of caffeoylquinic acids were also detected in burdock seeds, but only trace amounts of lignans were found in burdock roots. Burdock seeds contained higher concentrations of lignans and caffeoylquinic acids than burdock roots.

After anaerobic incubation of arctiin from burdock seeds with a human faecal suspension, six metabolites were formed, and their structures were identified as (−)-arctigenin, (2*R*,3*R*)-2-(3′,4′-dihydroxybenzyl)-3-(3″,4″-dimethoxybenzyl) butyrolactone, (2*R*,3*R*)-2-(3′-hydroxybenzyl)-3-(3″,4″-dimethoxybenzyl)butyrolactone, (2*R*,3*R*)-2-(3′-hydroxybenzyl)-3-(3″-hydroxy-4″-

methoxybenzyl) butyrolactone, (2*R*,3*R*)-2-(3′-hydroxybenzyl)-3-(3″,4″-dihydroxybenzyl) butyrolactone and (2*R*,3*R*)-2-(3′-hydroxybenzyl)-3-(3″-hydroxylbenzylbutyrolactone) or (−)-enterolactone (Xie et al. 2003).

The volatile oil from burdock seeds yielded 22 compounds, representing 80.4 % of the total composition (Aboutabl et al. 2013). The major compound was *E*-citral (28.8 %), followed by geraniol (20.3 %) and *Z*-citral (9.5 %). Other components were β-elemene 3.02 %, β-myrcene 2.82 %, methyl oleate 2.58 %, octadecanoic acid methyl ester 2.23 %, hexacosane 2.36 %, squalene 1.50 %, linalool 1.12 %, aromadendrene 0.76 %, eicosane 0.34 %, γ-cadinene 0.33 %, ethyl oleate 0.27 %, thymol 0.26 %, nonanal 0.23 %, methyl palmitate 1.59 %, β-costol 1.36 %, β-copaen-4α-ol 0.43 %, caryophyllene oxide 0.15 %, pentacosane 0.09 % and limonene 0.03 %.

Burdock fruit contained fatty oil, lappaurin (a yellow compound), arctiin (bitter glycosidic principle) and lappanaesthin (an anaesthetic substance) (List and Hörhammer 1972; Hoppe 1975). Two new sesquilignan derivatives, AL-D and AL-F, along with arctiin, arctigenin and matairesinol, were isolated from burdock fruit (Yamanouchi et al. 1976). AL-D was elucidated as2-[2-(3-methoxy-4-hydroxy)phenyl-3-hydroxymethyl-7-methoxy-2,3-dihydrobenzofuran-5-yl] methyl-3-(3-methoxy-4-hydroxy)-benzyl-buthyrolactone or 2-(3-methoxy-4-hydroxy) benzyl-3-[2-(3-methoxy-4-hydroxy)-phenyl-3-hydroxymethyl-7-methoxy-2,3-dihydrobenzofuran-5-yl] methyl-buthyrolactone. AL-F was found to be a stereoisomer of AL-D. Arctiin was isolated from the burdock fruit and then enzymolyzed into arctigenin (Sun et al. 1992). From the fruit, (+)-7,8-didehydroarctigenin, together with the known lignans (−)-arctigenin and (−)-matairesinol, was isolated (Matsumoto et al. 2006). The concentration range of 0.010–5.0 μg/mL for arctiin and 0.025–7.5 μg/mL for arctigenin was determined in burdock fruit (Liu et al. 2010). The recoveries were between 74.4 and 100 %. Two new neolignan glucosides named (7*S*,8*R*)-4,7,9,9′-tetrahydroxy-3,3′-dimethoxyl-7′-oxo-8-4′-oxyneolignan-4-*O*-β-D-glucopyranoside and (7′*S*,8′*R*,8*S*)-4,4′,9′-trihydroxy-3,3′-dimethoxy-7′,9-epoxylignan-7-oxo-4-*O*-β-D-glucopyranosyl-4′-*O*-β-D-glucopyranoside, together with two small molecular peptides named 3-benzyl-6-(1-hydroxyethyl)-2,5-piperazinedione and 3-benzyl-2,5-piperazinedione, were isolated from the burdock fruit extract (Yang et al. 2012).

Antioxidant Activity

The hydroethanolic extracts of burdock roots exhibited the strongest free radical scavenging activity, while the highest phenolic content was observed in Soxhlet extraction (Predes et al. 2011). The 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity and inhibition of Fe^{2+}-induced lipid peroxidation of burdock ethanol extract significantly increased in a dose-dependent manner (Lee 2011). For DPPH, its IC_{50} was 296 μg/assay (1.29 mg of dry sample) and Fe-induced lipid peroxidation inhibition IC_{50} was 1,759 μg/assay (7.65 mg of dry sample). Burdock extract also significantly inhibited the MDA-BSA conjugation reaction with an IC_{50} of 57.58 mg/assay (250 mg of dry sample). It exerted no inhibitory effects against the direct and indirect mutagenicities in *Salmonella typhimurium* TA98 and TA100.

Studies showed that *A. lappa* root extract possessed free radical scavenging activity (Lin et al. 1996). The IC_{50} of *A. lappa* extract on superoxide and hydroxyl radical scavenger activity was 2.06 and 11.8 mg/mL, respectively. Another in-vitro study confirmed that burdock roots possessed significant antioxidant activities both free radical and active oxygen scavenging activities (Duh 1998). Of the solvents used for extraction, water yielded the greatest amount of extract that exhibited the strongest antioxidant activity. Results revealed that water extracts of burdock (WEB) and hot water extracts of burdock (HWEB) were also active as oxygen scavengers and as secondary antioxidants. WEB and HWEB exhibited an 80 % scavenging effect on 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical and marked reducing power, indicating that WEB and HWEB act as primary antioxidants. Both extracts at a dose of 1.0 mg exhibited a 60.4–65.0 % scavenging effect on

superoxide and an 80.5 % scavenging effect on hydrogen peroxide. They also showed a marked scavenging effect on the hydroxyl radical. Another study showed that burdock root possessed significant DPPH free radical scavenging activity, which was mainly attributed to chlorogenic acid, whose free radical scavenging activity was similar to that of caffeic acid and higher than that of vitamin E (Chen et al. 2004). Peeling of the root greatly decreased the free radical scavenging activity and the concentrations of these two active phenolic components, due to elimination of the components in the discarded skin. Heat treatment slightly decreased the free radical scavenging activity, which was partially due to the degradation of chlorogenic acid. Dos et al. (2008) reported that the chloroform burdock root extract (250 μg/mL) and an active fraction B (100 and 250 μg/mL) exhibited free radical scavenging ability, inhibiting DPPH radical activity by 50 %, 20 % and 55 %, respectively. The DPPH radical scavenging activity of the burdock ethanol and hot water extracts after gamma irradiation were 54.56 and 59.21 % at 500 ppm, respectively, and the lipid oxidation of oil emulsion was delayed by the addition of the extracts (Lee et al. 2010).

In-vitro antioxidant assays demonstrated that a water-soluble polysaccharide (ALP1) from burdock root possessed moderate ABTS(+) scavenging activity, strong hydroxyl radical scavenging activity and strong ferrous ion-chelating activity (Liu et al. 2014). In in-vivo antioxidant assays, ALP1 administration significantly enhanced antioxidant enzyme activities and total antioxidant capacity, as well as decreased the levels of malondialdehyde (MDA) in both the serum and liver of ageing mice.

The metabolite 3′-desmethylarctigenin (3′-DMAG) transformed from arctiin or arctigenin by human intestinal bacterium named *Blautia* sp. AUH-JLD56 showed significantly higher 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity than that of the substrate arctigenin at the concentrations tested (Liu et al. 2013).

Five caffeoylquinic acid derivatives, 1-*O*-,5-*O*-dicaffeoylquinic acid (1), 1-*O*-,5-*O*-dicaffeoyl-3-*O*-succinylquinic acid (2), 1-*O*-,5-*O*-dicaffeoyl-4-*O*-succinylquinic acid (3), 1-*O*-,5-*O*-dicaffeoyl-3-*O*-,4-*O*-disuccinylquinic acid (4) and 1-*O*-,3-*O*-, 5-*O*-tricaffeoyl-4-*O*-succinylquinic acid (5) isolated from the root, showed antioxidant activity as measured in a hexane/2-propanol solution of methyl linoleate in the presence of a radical initiator (Maruta et al. 1995). The antioxidative efficiency was in the order of α-tocopherol < chlorogenic acid < caffeic acid <(1) = (2) = (3) = (4) <5.

Polysaccharides isolated from *Arctium lappa* var. Herkules were reported to inhibit peroxidation of soybean lecithin liposomes by OH radicals (Kardosová and Machová 2006). Of all the fractions of burdock leaf, the ethyl acetate fraction (EAF) exhibited the highest antioxidant activity (Lou et al. 2010a). Although tertiary butylhydroquinone (TBHQ) exhibited higher lipid peroxidation inhibitory activity than EAF, the reducing power, superoxide anion scavenging capability and DPPH radical and hydroxyl radical scavenging ability of EAF were higher than those of synthetic antioxidant (TBHQ). Furthermore, a synergistic antioxidant effect between EAF and TBHQ was first demonstrated by isobolographic analysis, indicating that EAF markedly enhanced the antioxidant efficiency of TBHQ.

TEAC values and total phenolic content for hydroalcoholic extracts of burdock seeds, leaves and roots ranged from 67.39 to 1.63 μmol Trolox equivalent/100 g dry weight (DW) and from 2.87 to 45 g of gallic acid equivalent/100 g DW, respectively (Ferracane et al. 2010). The main compounds of burdock extracts were caffeoylquinic acid derivatives, lignans (mainly arctiin) and various flavonoids.

Anticancer Activity

The dichloromethane extracts of burdock roots showed selective antiproliferative activity against K562, MCF-7 and 786-0 human cancer cell lines (Predes et al. 2011). In an earlier study, dichloromethane-soluble extract of *Arctium lappa* exhibited 100 % preferential cytotoxicity under the nutrient-deprived condition at a concentration of 50 μg/mL with virtually no cytotoxicity under nutrient-rich condition, and the active

principle isolated arctigenin (Awale et al. 2006). The human colon cancer HT29 cell viability was inhibited by burdock ethanol extract after gamma irradiation with up to 52.45 % at a 250 ppm level (Lee et al. 2010). Burdock root ethanol extract exhibited antileukaemic properties, inducing cell death of J-45.01 human acute T-cell leukaemia via apoptosis (Wegiera et al. 2012). Burdock root extract exhibited marked cytotoxic effect on the human erythroleukaemia cell line (K562) cell line and lymphocyte cells (Khakdan et al. 2013). Burdock root extract exhibited marked cytotoxic effect on the human erythroleukaemia (K562) cell line and lymphocyte cells (Khakdan et al. 2013).

Artigenin, from burdock fruit, was the most active lignin showing differentiation inducing activity against mouse myeloid leukaemia M1 cells at a concentration of 0.5 μm (Umehara et al. 1996a, b). Its aliphatic esters were more effective in inducing the differentiation of M1 cells than its aromatic esters. Especially, n-decanoate, which was the most active derivative, induced more than half of the M1 cells into phagocytic cells at a concentration of 2 μM. Of the three new dilignans isolated, arctignans G and H showed activities at 50–100 μm, whereas arctignan F showed only slight activity at these concentrations. Two active sesquilignans, lappaol E and arctignan A (an isolated of lappaol E), were found to possess the highest differentiation activities among the sesquilignans tested. Sesquilignans were less effective than lignans and dilignans showed even weaker activity. These lignoids were inactive towards a human acute promyelocytic leukaemia cell line (HL-60).

Arctigenin was found to be a potent inducer of apoptosis of human leukaemia HL-60 and K562 cells, modulated via caspase-3 activation and upregulation of Bax/Bcl-2 (Wang et al. 2008). Arctigenin significantly suppressed both constitutively activated and IL-6-induced STAT3 phosphorylation and subsequent nuclear translocation in cancer cells (Yao et al. 2011). Arctigenin dramatically promoted cisplatin-induced cell death in cancer cells, indicating that arctigenin enhanced the sensitivity of cancer cells to cisplatin mainly via STAT3 suppression.

The (−)-arctigenin, from burdock fruit, and its synthesised derivatives showed anticancer activity (Chen et al. 2012). A series of new (−)-arctigenin derivatives with variably modified O-alkyl groups exhibited were synthesised and their preferential cytotoxicity against human pancreatic cancer cell line PANC-1 under nutrient-deprived conditions (Kudou et al. 2013). The results showed that monoethoxy derivative 4i, diethoxy derivative 4 hours and triethoxy derivative 4 m showed the preferential cytotoxicities under nutrient-deprived conditions, which were identical to or more potent than (−)-arctigenin. In a mouse xenograft model, triethoxy derivative 4 m exhibited antitumour activity with the potency identical to or slightly more than (−)-arctigenin.

Arctigenin from burdock fruit appeared to be a new suppressive regulator of heat shock response (the activation of heat shock transcription factor, the induction of mRNA and the synthesis and accumulation of heat shock proteins) in mammalian cells and may be useful for hyperthermia cancer therapy (Ishihara et al. 2006). Arctigenin exhibited 100 % preferential cytotoxicity against nutrient-deprived cells at a concentration of 0.01 μg/mL. Arctigenin was also found to strongly suppress the PANC-1 tumour growth in nude mice, as well as the growth of several of the tested pancreatic cancer cell lines. Arctigenin blocked the activation of Akt induced by glucose starvation, a key process in the tolerance exhibited by cancer cells to glucose starvation. Purification of the selective cytotoxicity in burdock extract resulted in the identification of arctigenin as tumour-specific agent that showed cytotoxicity to human lung adenocarcinoma (A549), liver cancer (HepG2) and stomach cancer (KATO III) cells, with no cytotoxicity to several normal cell lines (Susanti et al. 2012). Arctigenin specifically inhibited the proliferation of cancer cells, which might consequently lead to the induction of apoptosis. Ethanol (70 %) burdock fruit extract showed potent antiproliferative activity against B-cell hybridoma cell line, MH60 (Matsumoto et al. 2006). Of its active components, (−)-arctigenin showed the most potent antiproliferative activity against MH60 cells via apoptosis (IC_{50}, 1.0 μM). The anaerobic metabolite of arc-

tiin, (2R,3R)-2-(3′-hydroxybenzyl)-3-(3″,4″-dihydroxybenzyl) butyrolactone, showed the most potent proliferative effect on the growth of MCF-7 human breast cancer cells in culture among 1 and 6 metabolites, while it showed inhibitory activity on estradiol-mediated proliferation of MCF-7 cells at a concentration of 10 μM (Xie et al. 2003). A retrospective cohort study in 510 women was conducted by Zick et al. (2006) to ascertain the effect of Essiac (a medicinal blend of burdock root, *Arctium lappa*, Indian rhubarb *Rheum palmatum*, sheep sorrel *Rumex acetosella* and the inner bark of slippery elm *Ulmus fulva* or *Ulmus rubra*) in women with breast cancer. Essiac has become one of the most popular herbal remedies for breast cancer treatment, secondary prevention, improving quality of life and controlling negative side effects of conventional breast cancer treatment. The study showed that Essiac did not appear to improve health-related quality of life (HRQOL) or mood states.

Studies demonstrated that arctigenin selectively promoted glucose-starved A549 tumour cells to undergo necrosis by inhibiting mitochondrial respiration (Gu et al. 2012a). In doing so, arctigenin elevated cellular level of reactive oxygen species (ROS) and blocked cellular energy metabolism in the glucose-starved tumour cells. It was also demonstrated that cellular ROS generation was caused by intracellular ATP depletion and played an essential role in the arctigenin-induced tumour cell death under the glucose-limiting condition. Further, the combination of arctigenin with the glucose analogue 2-deoxyglucose (2-DG) displayed preferential cell death-inducing activity against tumour cells compared to normal cells. Among the compounds isolated from burdock seeds and anaerobic metabolites, arctigenin and 3-*O*-demethylarctigenin (a metabolite) showed potent activity against human pancreatic cancer PANC-1 cells, with PC_{50} values of 1.75 and 4.38 μM, respectively, while matairesinol, lappaol B and 3,3′-di-*O*-demethyl-4′-dehydroxyarctigenin (metabolite) showed mild activity with PC_{50} values of 31.1, 30.9 and 38.7 μM, respectively (Tezuka et al. 2013). The proliferation of human gastric cancer cell line SNU-1 and AGS cells was significantly inhibited by arctigenin in a time- and dose-dependent manner (Jeong et al. 2011). Inhibition of cell proliferation by arctigenin was in part associated with apoptotic cell death. Also, arctigenin blocked cell cycle arrest from G_1 to S phase by regulating the expression of cell cycle regulatory proteins such as Rb, cyclin D1, cyclin E, CDK4, CDK2, p21Waf1/Cip1 and p15INK4b.

Arctigenin from burdock selectively arrested the proliferation of lung adenocarcinoma cells at the G0/G1 phase through the downregulation of NPAT protein expression (Susanti et al. 2013). This downregulation occurred via the suppression of either cyclin E/CDK2 or cyclin H/CDK7, while apoptosis was induced through the modulation of the Akt-1-related signalling pathway. Furthermore, a glutathione synthetase inhibitor specifically enhanced the cytotoxicity of arctigenin against the cancer cells. Arctigenin induced apoptosis of oestrogen receptor-negative human breast cancer MDA-MB-231 cells via the ROS/p38 MAPK pathway and epigenetic regulation of Bcl-2 by the upregulation of histone H3K9 trimethylation (Hsieh et al. 2014). Arctigenin treatment resulted in a significant and dose-dependent inhibition of human ovarian cancer OVCAR-3 and SKOV3 cell proliferation (Huang et al. 2014). Arctigenin-treated cells showed a four- to sixfold increase in the percentage of caspase-3-dependent apoptosis, compared to control cells. Arctigenin treatment significantly inhibited STAT3 phosphorylation and survivin and iNOS expression.

The methanolic extract of burdock seeds exhibited inhibitory activity against prostate cancer cell lines (Ming et al. 2004). Some of its bioactive compounds lappaol C, lappaol A and lappaol F also exhibited inhibitory activity against the LNCaP prostate cancer cell line with IC_{50} values of 8, 16 and 40 μg/mL, respectively. However, Zeng et al. (2005) found that arctiin may not exert significant modifying effect on prostate carcinogenesis in probasin/SV40 T antigen transgenic rats.

Arctiin, from burdock seeds, exerted a protective effect on 2-amino-1-methyl-6-phenylimidazo [4,5-b] pyridine (PhIP)-induced mammary carcinogenesis in female Sprague-Dawley rats in

the promotion period (Hirose et al. 2000). Contrariwise, arctiin may have a weak cocarcinogenic influence on 2-amino-3,8-dimethylimidazo [4,5-f] quinoxaline (MeIQx)-associated hepatocarcinogenesis in male rats. In addition, the results suggested that PhIP was a weak pancreatic carcinogen in female SD rats, targeting acinar cells. Matsuzaki et al. (2008) found that arctiin induced growth inhibition and dephosphorylated the tumour-suppressor retinoblastoma protein in human immortalised keratinocyte (HaCaT) cells by downregulation of cyclin D1 protein expression. The arctiin-induced suppression of cyclin D1 protein expression also occurred in various types of human tumour cells, including osteosarcoma; lung, colorectal, cervical and breast cancer; melanoma, transformed renal cells; and prostate cancer.

Lappaol F from burdock suppressed cancer cell growth in a time- and dose-dependent manner in human cancer cell lines of various tissue types by inducing G1 and G2 cell cycle arrest which was associated with strong induction of p21 and p27 and reduction of cyclin B1 and CDK1 (Sun et al. 2014). In contrast to its strong growth-inhibitory effects on tumour cells, lappaol F had minimal cytotoxic effects on non-tumorigenic epithelial cells tested. Also, it was demonstrated that lappaol F exhibited strong growth inhibition of xenograft tumours in nude mice. Lappaol F was well tolerated in treated animals without significant toxicity.

Crude extract (CE), ethyl acetate fraction (EAF) of burdock leaves and onopordopicrin compound isolated from burdock leaves exhibited in-vitro antiproliferative activity in human tumour cell line Caco-2 (Mello et al. 2010). The results of CC_{50} in Caco-2 cells were 347.6 μg/mL, 24.7 μg/mL 2 and 19.8 μg/mL for CE, EAF and onopordopicrin, respectively. Burdock leaf compounds tested in Caco-2 tumour cells showed antiproliferative activity with the following CC_{50} (μg/mL) values: onopordopicrin, 19.7 μg/mL; onopordopicrin with dehydromelitensin-8-(4′-hydroxymethacrylate), 24.6 μg/mL; dehydromelitensin-8-(4′-hydroxymethacrylate) with dehydromelitensin, 27 μg/mL; onopordopicrin with melitensin, 42 μg/mL; and loliolide 30 μg/mL (Machado et al. 2012). Compound dehydrovomifoliol showed no activity.

Antimutagenic Activity

A desmutagenic factor with molecular weight of >300,000 and polyanionic characteristics, isolated from burdock, reduced the mutagenicity of mutagens that were active without metabolic activation, such as 4-NO2-1,2-DAB and 2-NO2-1,4-DAB, as well as mutagens such as ethidium bromide, 2-aminoanthracene, Trp-P-1 and Trp-P-2 requiring S9 for metabolic activation (Morita et al. 1984). It is resistant to heat and proteolytic enzymes and sensitive to treatment with $MnCl_2$. The antimutagenicity against 3-amino-1,4-dimethyl-5H-pyrido[4,3-b]indole and 2-nitrofluorene was also found for burdock ethanol extract after gamma irradiation (Lee et al. 2010).

Antimicrobial Activity

The ethyl acetate fraction of *A. lappa* inhibited the growth of endodontic microorganisms *Pseudomonas aeruginosa*, *Escherichia coli*, *Lactobacillus acidophilus*, *Streptococcus mutans* and *Candida albicans* in-vitro (Gentil et al. 2006). Antimicrobial activity of extracts from leaves of burdock exhibited a great microbial inhibition potential against the tested endodontic pathogens: *Enterococcusfaecalis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Bacillus subtilis* and *Candida albicans* (Pereira et al. 2005). The data from minimum inhibitory concentration (MIC) values showed that ethyl acetate (EF), *n*-butanol (BF) and water (WF) fractions of burdock leaves effectively inhibited the growth of all test food-borne bacterial pathogens (*Staphylococcus aureus*, *Streptococcus pneumoniae*, *Bacillus subtilis*, *Escherichia coli*, *Shigella dysenteriae* and *Salmonella typhimurium*), the antibacterial activity of EF being much greater than BF and WF. The time–kill study indicated that EF exhibited significant bactericidal activity against all the six pathogens. For all the fractions, the antibacterial capacity had a significant cor-

relation with total phenolic content, suggesting that the activities were probably due to the combined action of phenolic compounds. Two purified active phenolic compounds (chlorogenic acid, rutin) were obtained and identified.

Burdock extract was microbicidal for *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Streptococcus mutans*, *Candida albicans*, *Candida tropicalis* and *Candida glabrata* in planktonic cultures, microbiostatic for biofilms and not cytotoxic to the macrophages (RAW 264.7) (de Oliveira et al. 2014).

The volatile constituents of burdock leaves and roots showed weak to moderate antimicrobial activity against bacteria (*Escherichia coli* and *Bacillus subtilis*) and higher antifungal activity (*Candida albicans* and *Aspergillus niger*) in comparison with the standards used (Aboutabl et al. 2013). The volatile constituents of the seeds showed moderate antimicrobial activity against bacteria and weak activity against fungi. The volatile constituents of the leaves and the roots show a minimum inhibitory concentration of 250 µL/mL against the two fungi which were lower than that of the standard, Flucoral 1,000 µL/ mL.

Antiviral Activity

Arctigenin at the concentration of 100 µg/kg and 10 µg/kg for the intranasal treatment markedly inhibited the lung consolidation of mice pneumonia caused by the infection of influenza virus (Yang et al. 2005). Arctigenin at the concentration of 100 µg/kg prolonged the survival time of mice infected with influenza virus. Arctiin and its aglucone, arctigenin from burdock fruits, exhibited potent in-vitro antiviral activities against influenza A virus (IFV) (Hayashi et al. 2010). Arctiin was orally effective against either IFV-inoculated normal or 5-fluorouracil (5-FU)-treated mice, being less effective as compared with oseltamivir. Arctiin produced a larger amount of virus-specific antibody than those of control and oseltamivir in sera collected from 5-FU-treated mice. Further, oral treatment of 5-FU-treated mice with arctiin did not induce any resistant viruses, although the same treatment with oseltamivir induced resistant viruses at a 50 % frequency. When the combination of arctiin and oseltamivir was administered to normal mice infected with IFV, the virus yields in both bronchoalveolar lavage fluids and lungs were significantly reduced relative to those in the mice treated with arctiin or oseltamivir alone.

Prebiotic Activity

Burdock inulin (B-INU) significantly stimulated the growth of *Bifidobacteria* in Man–Rogosa–Sharp medium, anaerobically (Li et al. 2008). Compared with chicory inulin (C-INU), long-chain inulin (L-INU) and fructooligosaccharides (FOS), 1 % (w/v) B-INU promoted the specific growth rate of beneficial bacteria. In-vivo, B-INU significantly increased the number of lactobacilli and bifidobacteria in caecal content. Mice fed with B-INU, C-INU and FOS for 14 days had greater number of caecal beneficial bacterial population than those fed with L-INU for 14 days. Additionally, all fructans did not cause any side effects, such as eructation and bloating. Results indicated that inulin extracted from edible burdock showed prebiotic properties that could promote health.

Anti-inflammatory Activity

Subcutaneous administration of *A. lappa* root crude extract significantly decreased carrageenin-induced rat paw oedema. When simultaneously treated with CCl_4, it produced pronounced activities against CCl_4-induced acute liver damage (Lin et al. 1996). Cho et al. (2004) reported that arctigenin inhibited phosphorylation of MAP kinases ERK1/ERK2, p38 kinase and JNK and their activities in RAW 264.7 cells treated with lipopolysaccharide (LPS). Arctigenin potently inhibited the activity of MKK1 in-vitro with the IC_{50} value of 1 nM. Additionally, arctigenin blocked TNF-α production and decreased the level of TNF-α mRNA in the cells exposed to LPS. The results showed that arctigenin inhibited the activation of

MAP kinases including ERK1/ERK2, p38 kinase and JNK through the inhibition of MKK activities, leading to AP-1 inactivation, thus partially contributing to the inhibition of TNF-α production. Kim et al. (2008) demonstrated that diarctigenin from burdock seeds inhibited the production of NO, prostaglandin E_2, tumour necrosis factor-alpha and interleukin (IL)-1beta and IL-6 with IC_{50} values of 6–12 μM in zymosan- or lipopolysaccharide (LPS)-activated macrophages. Diarctigenin attenuated zymosan-induced mRNA synthesis of inducible NO synthase (iNOS) and also inhibited promoter activities of iNOS and cytokine genes in the cells. The results showed that diarctigenin downregulated zymosan- or LPS-induced inflammatory gene transcription in macrophages by direct inhibition of the DNA-binding ability of NF-κB. Lignans lappaol F and diarctigenin, from burdock seeds, strongly inhibited NO production in the LPS-stimulated RAW 264.7 cells with IC_{50} values of 9.5 and 9.6 μM, respectively (Park et al. 2007).

In-vitro studies showed that methanolic extracts of burdock (MEB) and their major components, chlorogenic acid and caffeic acid, exhibited marked antioxidant activity against oxidative damage of liposome, deoxyribose and protein (Wang et al. 2007). At a concentration of 500 μg/mL, the inhibitory effect of MEB on low-density lipoprotein oxidation was 66.9 % compared to the control. MEB, at 200 μg/mL, not only enhanced glutathione (GSH) levels but also increased the activity of GSH reductase, GSH peroxidase, GSH transferase and catalase. MEB directly scavenged nitric oxide in a concentration-dependent fashion. Moreover, MEB showed a reducing effect on nitric oxide production of lipopolysaccharide (LPS)-induced RAW 264.7 cells and inhibited the expression of inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2). The expression of iNOS and COX-2 mRNA in activated macrophages was suppressed by a high concentration (500 μg/mL) of MEB by downregulating NF-κB activation. The results suggested that MEB attenuated excessive NO generation at inflammatory sites as well as in cardiovascular disease.

Arctigenin, a lignan from *Arctium lappa* seeds, potently inhibited lipopolysaccharide (LPS)-stimulated NO production and proinflammatory cytokine secretion, including TNF-α and IL-6 in a dose-dependent manner in cultured macrophage RAW 264.7 cells and THP-1 cells (Zhao et al. 2009). Arctigenin also strongly suppressed the expression of iNOS and iNOS enzymatic activity, whereas the expression of COX-2 and COX-2 enzymatic activity was not affected by arctigenin. Arctigenin was found to inhibit type I–IV allergic inflammation and proinflammatory enzymes in-vitro and in-vivo (Lee and Kim 2010). Arctigenin significantly inhibited the heterologous passive cutaneous anaphylaxis induced by ovalbumin in mice and compound 48/80-induced histamine release from rat peritoneal mast cells. Arctigenin significantly inhibited reversed cutaneous anaphylaxis and the Arthus reaction to sheep's red blood cells, decreasing the haemolysis titre, the haemagglutination titre and the plaque-forming cell number for SRBCs. Additionally, arctigenin significantly inhibited delayed-type hypersensitivity and the formation of rosette-forming cells. Contact dermatitis induced by picryl chloride and dinitrofluorobenzene was significantly inhibited by surface treatment with arctigenin (0.3 mg/ear). Furthermore, arctigenin dose dependently inhibited proinflammatory enzymes, such as cyclooxygenase-1 and cyclooxygenase-2, 5-lipoxygenase, phospholipase A2 and phosphodiesterase.

Arctium lappa extract significantly reduced degranulation and biosynthesis of cysleukotrienes of human basophils in peripheral blood mononuclear cells (PBMCs) with IC_{50} of 8.3 and 11.4 μg/mL, respectively (Knipping et al. 2008). A fraction from the extract inhibited beta-hexosaminidase release (IC_{50} = 22.2 μg/mL). Topical administration of an aqueous burdock extract (5 mg/ear) on the ear of whey-sensitised mice 4 hours before challenge with whey in the ear inhibited acute ear swelling by 50 % in an in-vivo cow's milk allergic model. Burdock seed ethanol extract ameliorated high-fat/high-cholesterol diet-induced vascular dysfunction in rats through protection of vascular relaxation and suppression of vascular inflammation (Lee et al. 2012). Treatment with low or high doses of burdock extract markedly attenuated plasma levels of triglycerides and augmented plasma levels of high-density lipoprotein (HDL) in HFCD-fed

rats. Chronic treatment with the extract markedly reduced impairments of acetylcholine (ACh)-induced relaxation of aortic rings, significantly lowered systolic blood pressure (SBP) and maintained smooth and flexible intimal endothelial layers in HFCD-fed rats. Chronic treatment with the extract suppressed upregulation of intercellular adhesion molecule (ICAM)-1, vascular cell adhesion molecule (VCAM)-1 and E-selectin in the aorta and also suppressed increases in matrix metalloproteinase (MMP)-2 expression.

Oral administration of lactone sesquiterpene onopordopicrin-enriched fraction (ONP fraction) from *Arctium lappa* exerted marked protective effects in acute experimental colitis induced by 2,4,6-trinitrobenzene sulfonic acid (de Almeida et al. 2013). ONP fraction (25 and 50 mg/kg) treatment significantly reduced the macroscopic inflammation scores and morphological alterations associated with an increase in the mucus secretion. Similarly, the degree of neutrophil infiltration and the cytokine levels were significantly ameliorated and COX-2 overexpression was reduced by ONP fraction. Arctigenin ameliorated inflammation in-vitro in lipopolysaccharide (LPS)-induced peritoneal macrophages and in-vivo in LPS-induced systemic inflammation as well as 2,4,6-trinitrobenzene sulfonic acid (TNBS)-induced colitis in mice by inhibiting the PI3K/AKT pathway and polarising M1 macrophages to M2-like macrophages (Hyam et al. 2013).

Intragastric administration of the herbal preparation comprising *Arctium lappa* roots, *Sophora japonica* fruits, *Acorus calamus* roots, *Urtica dioica* leaves and *Humulus lupulus* fruits reduced severity of the exudation phase of inflammation in the limbs of animals (37.3 %) and inhibited pulmonary oedema (21.0 %) (Galkin et al. 2013). The phytopreparation reduced the weight of the granulation–fibrous tissue by 50.6 %.

Anti-allergic Activity

Burdock treatment showed significant improvement in itching behaviour in NC/Nga mice induced by 2,4-dinitrofluorobenzene (DNFB) (Kim et al. 2010a). However, burdock treatment showed neither significant improvement on allergic dermatitis lesions nor in IL-4 and INF-γ measurement. Butanol burdock extract significantly inhibited β-hexosaminidase release in RBL-2H3 cells and suppressed mRNA expression and protein secretion of IL-4 and IL-5 induced by ConA-treated primary murine splenocytes (Sohn et al. 2011). Additionally, the extract (100 μg/mL) suppressed not only the transcriptional activation of NF-κB but also the phosphorylation of MAPKs in ConA-treated primary splenocytes. The results supported the hypothesis that burdock extract may have beneficial effects in the treatment of allergic diseases, including atopic dermatitis.

Antihyperglycaemic/Antidiabetic Activity

Burdock methanol and ethyl acetate extracts exhibited an inhibitory activity of α-glucosidase (Miyazawa et al. 2005). The inhibitory compound isolated from the ethyl acetate extract was identified as sitosterol-β-D-glucopyranoside. It inhibited 97.3 % of α-glucosidase activity at a concentration of 200.0 μmol/mL, and the ID_{50} (50 % inhibition dose) value was 30 μmol/mL. In addition, the inhibitory compounds from the ethyl acetate extract were also identified as methyl palmitate (2), methyl linoleate (3) and methyl linoleneate (4) by GC-MS analysis. Compounds 2–4 inhibited 73.4 %, 66.5 % and 68.5 % of α-glucosidase activity at a concentration of 200 μmol/mL, and the ID_{50} values were 52.8, 47.5 and 46.7 μmol/mL.

Arctigenin from burdock was found to be an effective endoplasmic reticulum (ER) alleviator, which protected cells against ER stress through activating AMPK, thus attenuating protein translation and reducing ER load (Gu et al. 2012b). ER stress had been linked to obesity and to be a central feature of peripheral insulin resistance and type 2 diabetes at the molecular, cellular and organismal levels (Ozcan et al. 2004).

Administration of total lignans from burdock fruit to alloxan-diabetic rats and mice for 10 days elicited significant reductions in plasma glucose, triglycerides and total cholesterol, and glucose tolerance, serum insulin level and HDL cholesterol

were elevated without the risk of hypoglycaemia (Xu et al. 2008). Burdock is considered to be a source of inulin that is converted into fructose and short fructose chains that penetrate into the circulatory system upon entering the gastrointestinal tract (Azizov et al. 2012). The remaining uncleaved part of inulin and cellulose is capable of absorbing a significant amount of dietary glucose and preventing it from being assimilated into the blood. This helps to reduce the sugar level in the blood after meals. Study showed that total lignans from Fructus Arctii (TLFA) exerted significant hypoglycaemic potential in Goto-Kakizaki rats, a spontaneous type 2 diabetes animal model, via stimulation of insulin secretion, promoting the release of serum glucagon-like peptide-1 (GLP-1) and decreasing intestinal absorption of glucose (Xu et al. 2014).

Arctiin treatment of male Sprague-Dawley rats with streptozotocin-induced diabetic retinopathy significantly decreased glycosylated haemoglobin (HBA1c) level, and the serum glucose level was also decreased in the rats treated with the highest dose of arctiin (Lu et al. 2012). Further, treatment with arctiin ameliorated retinal oedema, detachment of the retina and VEGF expression in the retina. Also, arctiin increased the viability of retinal microvascular endothelial cells in-vitro.

Huang et al. (2012) reported that arctigenin activated muscle uptake of glucose and inhibited hepatocyte gluconeogenesis and lipogenesis by reducing mitochondrial respiration and inducing AMP-activated protein kinase (AMPK) activity. AMPK, a major regulator of energy homeostasis, had been known to be activated by different glucose-lowering agents. They found that arctigenin improved glucose and lipid metabolism in ob/ob mice. They thus suggested that arctigenin may represent a valuable lead compound for developing innovative glucose-lowering molecules.

Treatment with arctiin significantly decreased the levels of 24 hour urinary albumin, prevented the sclerosis of glomeruli and effectively restored the glomerular filtration barrier damage by upregulating the expression of nephrin and podocin and downregulating heparanase level in streptozotocin (STZ)-induced diabetic nephropathic rats (Ma et al. 2013).

Antiobesity Activity

Kuo et al. (2012) found that burdock root treatment significantly reduced body weight in rats. The active n-hexane root fraction contained components with the most effective hypolipidaemic potential in human hepatoma HepG2 cells. The fraction decreased the expression of fatty acid synthase (FASN) and inhibited the activity of acetyl-coenzyme A carboxylase (ACC) by stimulating AMP-activated protein kinase (AMPK) through the LKB1 pathway.

Consumption of the burdock and *Aspergillus awamori*-fermented burdock diets significantly elevated faecal IgA and mucins (indices of intestinal immune and barrier functions) and reduced faecal lithocholic acid (a risk factor for colon cancer) in rats fed a high-fat (HF) diet (Okazaki et al. 2013). The fermented burdock diet markedly elevated caecal *Bifidobacterium* and organic acids, including lactate, acetate, propionate and butyrate, and reduced faecal deoxycholic acid (a risk factor for colon cancer) and perirenal adipose tissue weight, but the burdock diet did not. The results suggested that consumption of fermented burdock improved the intestinal luminal environment and suppressed obesity in rats fed a high-fat diet.

Nephroprotective Activity

In-vivo studies found that the combined use of *Astragalus* and *Arctium* may ameliorate the condition of diabetic nephropathy in streptozotocin (STZ)-induced rats by inhibiting the activation of the reactive oxygen species (ROS) content and nuclear transcription factor-kappaB expression (NF-κB) in renal tissue (Wang and Chen 2008).

Wu et al. (2009) found that arctiin from *Arctium lappa* exerted ameliorative effect on rat glomerulonephritis induced by cationic bovine serum albumin. After oral administration of arctiin (30, 60, 120 mg/kg/d) for 3 weeks, the levels of serum creatinine (Scr) and blood urea nitrogen (BUN) and 24 hour urine protein content markedly decreased, while endogenous creatinine clearance rate (ECcr) significantly increased. The

parameters of renal lesion, hypercellularity, infiltration of polymorphonuclear leukocyte (PMN), fibrinoid necrosis, focal and segmental proliferation and interstitial infiltration, were reversed. Additionally, arctiin markedly reduced the levels of malondialdehyde (MDA) and proinflammatory cytokines including interleukin 6 (IL-6) and tumour necrosis factor (TNF-α), suppressed nuclear factor-kappaB p65 (NF-κB) DNA-binding activity and enhanced superoxide dismutase (SOD) activity.

Gastroprotective Activity

Oral administration of burdock root chloroform extract (100 mg/kg) per day for 7 days reduced the chronic gastric ulceration induced by acetic acid by 52 % in animals (Dos Santos et al. 2008). Intraduodenal administration of the extract (100, 300 and 600 mg/kg) reduced the total acidity of gastric secretion by 22 %, 22 % and 33 %, respectively, while IP administration (10, 30 and 100 mg/kg) inhibited total acidity by 50 %, 60 % and 67 %, respectively. In-vitro studies confirmed that the extract protected animals from gastric lesions by reducing gastric acid secretion via inhibition of gastric H+, K+-ATPase. In another study, oral administration of burdock powder for 7 days exerted a protective effect against dextran sulfate sodium-induced colitis in BALB/c mice (Huang et al. 2010). Burdock treatment could prevent mucosal oedema, submucosal erosions, ulceration, inflammatory cell infiltration and colon damage. Furthermore, immunohistochemistry analysis showed that the levels of the inflammatory cytokines, interleukin 6 (IL-6) and tumour necrosis factor-alpha (TNF-α) in colonic sections, were also decreased in burdock-treated groups.

Oral administration of burdock root ethanol extract (1, 3, 10 and 30 mg/kg) reduced the gastric lesion area in 29.2 %, 41.4 %, 59.3 % and 38.5 %, respectively, and at 10 mg/kg promoted significant regeneration of the gastric mucosa in rats (da Silva et al. 2013). Burdock extract did not increase the gastric mucus content but restored the superoxide dismutase activity, prevented the reduction of glutathione levels, reduced lipid hydroperoxide levels, inhibited the myeloperoxidase activity and reduced the microvascular permeability. Additionally, burdock extract reduced the free radical generation and increased scavenging of 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radicals in-vitro. The main compound in the extract was found to be a series of hydroxycinnamoylquinic acid isomers. Onopordopicrin (ONP)-enriched fraction from burdock leaves (50 mg/kg, p.o.) significantly inhibited the mucosal injury induced by ethanol/HCl solution (75 %), indomethacin/bethanechol (68.9 %) and stress (58.3 %) in rodents (de Almeida et al. 2012). ONP fraction significantly increased serum somatostatin levels (82.1 vs. control group 12.7 pmol/L) and decreased serum gastrin levels (62.6 vs. control group 361.5 μg/mL). Mucus production was not significantly altered by the ONP fraction. The results suggested an antisecretory mechanism involved with the antiulcerogenic effect of the ONP fraction.

Crude burdock seed extracts and isolated compounds showed a strong antibacterial activity against a clarithromycin-resistant *Helicobacter pylori* strain (Kamkaen et al. 2006). Specifically, at a concentration of 50 μg/mL, 3′-demethyl arctigenin and arctigenin each exerted a 100 % inhibition against *H. pylori* compared to a standard amoxicillin (5 μg/mL) and clarithromycin (1 μg/mL), while arctigenin glucoside and crude extract showed a 95 % and 86 % inhibition, respectively. In clinical trials of 27 patients with peptic ulcers, of 20 patients that took burdock essence, 17 (85 %) recovered completely and 3 (15 %) did not (Wu et al. 2010). In the experimental group, the ulcer wounds of the three patients who had taken burdock essence did not completely heal, but wounds were reduced in size by 30, 75 and 33 %. Moreover, 10 out of 11 patients who originally were positive for *Helicobacter pylori* infections no longer had the pathogen by the end of the trial. These results indicate that burdock essence has an inhibitory effect on *H. pylori*. The study confirmed that two tablets (500 mg/tablet) of burdock essence taken orally three times a day after meals could help eliminate *H. pylori* infection and promote the therapeutic effect of conventional medication on gastric mucosal repair in

gastrointestinal ulcer patients. Clinical trial has proved that greater burdock can function as an adjuvant therapy for patients with gastric ulcer caused by *Helicobacter pylori* (Ku et al. 2013). The concentration of chlorogenic acids in the essence degraded from 29.29 to 28.29 μg/g during the accelerated storage tests conducted for up to 6 months. Further, the concentration of chlorogenic acids degraded from 29.29 to 28.57 μg/g during the long-term storage tests conducted for a period of up to 12 months. In both these tests, no changes were observed in trait, scent and colour of the great burdock essence compounds.

Hepatoprotective Activity

Studies showed that burdock root extract could protect the liver cells from CCl_4 or acetaminophen-induced liver damages, perhaps by its antioxidative effect on hepatocyte (Lin et al. 2000). Burdock suppressed the SGOT and SGPT elevations induced by CCl_4 or acetaminophen in a dose-dependent manner and alleviated the severity of liver damage based on histopathological observations. Also, burdock decreased the malondialdehyde (MDA) content in CCl_4 or acetaminophen-intoxicated mice. Lin et al. (2002) also found that *A. lappa* significantly improved various pathological and biochemical parameters in rats which were exacerbated by ethanol plus CCl_4-induced liver damage, such as the ethanol plus CCl_4-induced decreases in total cytochrome P450 content and NADPH–cytochrome c reductase activity, increases in serum triglyceride levels and lipid peroxidation (the deleterious peroxidative and toxic malondialdehyde metabolite may be produced in quantity) and elevation of serum transaminase levels. The results suggested that the hepatotoxicity induced by ethanol and potentiated by CCl_4 could be alleviated with 1 and 7 days of burdock treatment.

Neuroprotective Activity

Pretreatment of rats with arctigenin for 7 days before transient occlusion of the middle cerebral artery and reperfusion significantly reduced cerebral infarction and improved neurological outcome by suppressing the activation of microglia and decreased the expression of interleukin (IL)-1β and tumour necrosis factor (TNF)-α (Fan et al. 2012).

Antihypertensive Activity

Ca^{2+} antagonists had been used as therapeutic agents to treat coronary heart diseases and hypertension. Potent Ca^{2+} antagonist activity was found in hot aqueous burdock fruit extract in the methanol fraction (Ichikawa et al. 1986). Of the lignans tested the order of inhibitory potencies was butanolides > bis-tetrahydrofurans = steganes. Other lignans tested, tetrahydrofuran and aryltetrahydronaphthalene, had no significant activity. The most potent activity occurred in trachelogenin, a typical butanolide; the calculated IC_{50} and pA_2 were 1.1×10^{-6} M and 6.60, respectively. Trachelogenin had a potent and long-lasting antihypertensive effect on spontaneously hypertensive rats. Arctigenin was less potent. Lappaols C, E, F and H had lower inhibitory activity.

Antiatherosclerotic Activity

Studies found that arctigenin promoted cholesterol efflux in oxidised low-density lipoprotein (oxLDL)-loaded THP-1 macrophages through upregulation of ATP-binding cassette transporter A1 (ABCA1), ABCG1 and apoE, which was dependent on the enhanced expression of peroxisome proliferator-activated receptor gamma (PPAR-γ) and liver X receptor alpha (LXR-α) (Xu et al. 2013). Cholesterol efflux from macrophages is a critical mechanism to prevent the development of atherosclerosis.

Antiplatelet Activity

The hot aqueous extract of *A. lappa* seeds including it active constituents arctigenin and arctigenin methyl ether showed significant inhibitory activity on binding of platelet-activating factor (PAF) to rabbit platelets (Iwakami et al. 1992). Burdock seed

extract inhibited PAF binding to 74 % at 200 μg/mL concentration. IC_{50} for PAF binding was 2.9 μM for arctigenin and 0.56 μM for arctigenin methyl ether.

Antitussive Activity

A fructofuranan of the inulin type, isolated from burdock roots, exhibited antitussive activity in cats (Kardosová et al. 2003). The fructan was found to be equally active as some non-narcotic, synthetic preparations used in clinical practice to treat coughing, and in mitogenic and comitogenic tests, its biological response was comparable to that of the commercial zymosan immunomodulator. A polysaccharide from *Arctium lappa* L., var. Herkules was reported to have antitussive activity (Sutovska et al. 2007).

Antiurolithiatic Activity

Studies by Grases et al. (1994) reported that *Arctium lappa* was one of the seven plants found to have antiurolithiatic activity in female Wistar rats and that the beneficial effect could be attributable to the presence of saponins.

Anti-ageing Activity

Animal studies showed that the anti-ageing effect of Niubangen (burdock root) decoction was mainly attributed to the enhancement of superoxide dismutase activity in liver tissues and blood serum of decoction-fed rats and reduction in malondialdehyde in brain tissue and blood serum and lipofuscin contents (Liu et al. 2005b). Studies by Knott et al. (2008) showed that topical treatment with a natural *A. lappa* fruit extract significantly improved the metabolism of the dermal extracellular matrix and led to a visible wrinkle reduction in-vivo. In-vitro studies on human dermal fibroblasts and monocyte-derived dendritic cells supplemented with pure arctiin showed relative to untreated control cells a stimulation of collagen synthesis and a decrease in interleukin 6 and tumour necrosis factor-alpha concentration, respectively.

Anti-tyrosinase Activity

Water extracts of Fructus Arctii (burdock seeds) were shown to inhibit tyrosinase activity in-vitro and melanin content in α-melanocyte stimulating hormone-stimulated cells to similar levels as the well-known kojic acid and arbutin, respectively (Park et al. 2013). Melanogenic inhibitory activity was also identified in-vivo with zebrafish embryo. It was found that arctigenin, the active constituent, downregulated cAMP and the tyrosinase enzyme through its gene promoter and subsequently upregulated extracellular signal-regulated kinase activity by increasing phosphorylation in the melanogenesis signalling pathway, leading to a lower melanin content.

Memory Enhancement Activity

Arctigenin from burdock seeds at doses of 30 and 60 mg/kg (p.o.) potently reversed scopolamine-induced memory deficits in mice by 62 % and 73 %, respectively, in a passive avoidance test (Lee et al. 2011). Arctigenin more potently inhibited AChE activity than arctiin. Arctigenin also significantly reversed scopolamine-induced memory deficits of mice in the Y-maze and Morris water maze tests indicating that arctigenin may ameliorate memory deficits by inhibiting acetylcholinesterase (AChE) activity.

Treatment of arctigenin in mice highly decreased β-amyloid (Aβ)-induced neurodegeneration by decreasing Aβ formation and senile plaques and efficiently ameliorated Alzheimer's disease mouse memory impairment (Zhu et al. 2013). The results strongly highlighted the potential of arctigenin in anti- Alzheimer's disease.

Adaptogenic Activity

Administration of arctigenin efficiently improved mouse endurance on the treadmill as reflected by the increased fatigue time and distance, and potently enhanced mitochondrial biogenesis and fatty acid oxidation (FAO)-related gene expression in muscle tissues (Tang et al. 2011). Arctigenin strongly increased AMP-activated

protein kinase (AMPK) phosphorylation via calmodulin-dependent protein kinasekinase (CaMKK) and serine/threonine kinase 11(LKB1)-dependent pathways and subsequently upregulated its downstream pathway in both H9C2 and C2C12 cells. The results suggested that arctigenin might be used as a potential lead compound for the discovery of the agents with mimic exercise training effects to treat metabolic diseases.

Antiparasitic Activity

Studies in mice showed that betamethasone and burdock treatments were found to be ineffective in protecting against intestinal lesions induced by the parasite *Angiostrongylus costaricensis*, a parasite that causes abdominal angiostrongyliasis in humans (Fante et al. 2008).

Photoprotective Activity

Burdock fruit fermented with the basidiomycetous fungus *Grifola frondosa* (G-FAE) exhibited photoprotective potential when tested in human dermal fibroblasts (HDF) exposed to ultraviolet A (UVA) (Kim et al. 2010b). G-FAE had an inhibitory effect on human interstitial collagenase (matrix metalloproteinase, MMP-1) expression in UVA-irradiated HDF. The treatment of UVA-irradiated HDF with fermented burdock fruit resulted in a dose-dependent decrease in the expression level of MMP-1 mRNA. G-FAE also showed notable stimulation of collagen biosynthetic activity for fibroblasts. Pretreatment with arctiin prior to UVB irradiation reduced UVB-induced apoptosis, cell migration defects and DNA damage in normal human dermal fibroblast (NHDF) cells (Lee et al. 2014). It was also found that arctiin-induced UVB protection was associated with altered miRNA expression profiles in HNDF cells.

Burn/Wound Healing Activity

In a pilot study of five Amish with first- and second-degree burns, burns and wounds, burdock leaf dressing changes caused minimal or no pain; none of the burns became infected, and healing times averaged less than 14 days (Amish Burn Study Group et al. 2014). The use of this herbal remedy appeared to be an acceptable alternative to conventional burn care for these types of burns.

Enhancement of Sexual Behaviour Activity

Oral administration of burdock root extract at 600 and 1,200 mg/kg body weight to male albino rats significantly increased the frequencies of mount, intromission and ejaculation frequency (Cao et al. 2012). The latencies of mount and intromission were significantly reduced and ejaculation latency was prolonged. Administration of the extract also reduced the post-ejaculatory interval. The extract significantly increased the frequencies of all components of penile reflexes as well as serum testosterone levels, compared with the distilled water controls. The results thus supported the traditional use of burdock root extract for treating impotence and sterility.

Immunomodulatory Activity

Arctigenin inhibited the primary human T lymphocyte proliferation activated by anti-CD3/anti-CD28 Ab and decreased the gene expression interleukin 2 (IL-2) and interferon-γ (IFN-γ) production in a concentration-dependent manner (Tsai et al. 2011). Baicalin, a natural compound from burdock, and its derivative genistin, selectively inhibited the activities of terminal deoxyribonucleotidyltransferase (TdT) and truncated TdT (the so-called pol beta core domain) in which the BRCT motif was deleted in its N-terminal region (Uchiyama et al. 2005). The IC_{50} value of baicalin to TdT was 18.6 μM. The activity of genistin was higher than baicalin although its IC_{50} value was weaker (28.7 μM). Baicalin had previously been reported as an anti-inflammatory or antipyretic agent; terminal deoxyribonucleotidyltransferase had been suggested to play a role in immunological diversity (Coleman et al. 1974).

The phytopreparation comprising *Arctium lappa* roots, *Sophora japonica* fruits, *Acorus calamus* roots, *Urtica dioica* leaves and *Humulus lupulus* fruits activated macrophages (50–400 μg/mL), decreased the number of flattened cells, increased the number of rounded cells and increased the production of oxidative metabolites (by 26 % compared with intact cells) (Galkin et al. 2013). The herbal drug (0–300 μ g/mL) increased cytokine secretion by human blood cells (interleukin 2 and interferon-γ).

Ocular Protective Activity

Total lignan from burdock fruit exhibited aldose reductase, suggesting its preventive potential on diabetic complications upon long-term administration (Xu et al. 2010).

Antiarthritic/Antiosteoporotic Activity

Studies by Kim et al. (2012) found that arctigenin may be useful for treating rheumatoid arthritis and osteoporosis. Arctigenin inhibited receptor activator of nuclear factor-κB ligand (RANKL)-mediated osteoclast differentiation in bone marrow macrophages in a dose-dependent manner and suppressed RANKL-mediated bone resorption. Additionally, the expression of typical marker proteins, such as NFATc1, c-Fos, TRAF6, c-Src and cathepsin K, was significantly inhibited. Arctigenin inhibited the phosphorylation of ERK1/ERK2, but not p38 and JNK, in a dose-dependent manner. Arctigenin also dramatically suppressed immunoreceptor tyrosine-based activation motif-mediated costimulatory signalling molecules, including Syk and PLCγ2, and Gab2. Arctigenin strongly inhibited the activation of Syk through RANKL stimulation. Furthermore, arctigenin prevented osteoclast differentiation in the calvarial bone of mice following stimulation with lipopolysaccharide.

Arctigenin strongly inhibited receptor activator of nuclear factor-κB ligand (RANKL)-induced osteoclast-like cell formation, differentiation and function by suppressing both calcineurin-dependent pathway and osteoblastic cell-dependent nuclear factor of activated T cells, cytoplasmic 1 (NFATc1) pathway, a key transcription factor for osteoclastogenesis (Yamashita et al. 2014).

Pharmacokinetic Studies

Nose et al. (1992) found that the lignins arctiin and tracheloside, from burdock seeds, were stable in gastric juice, and arctiin was rapidly transformed to arctigenin in rat large intestinal flora, followed by conversion to the major metabolite, 2-(3″,4″-dihydroxybenzyl)-3-(3′,4′-dimethoxybenzyl)-butyrolactone. Tracheloside also decreased dependently with time and was converted to trachelogenin and its major metabolite, 2-(3″,4″-dihydroxybenzyl)-3-(3′,4′-dimethoxybenzyl)-2-hydroxybutyrolactone. Further, they found that arctiin or tracheloside was transformed to at least two metabolites in the rat gastrointestinal tract, and after absorption from the intestine, metabolite 2 was converted into metabolite 1 through methylation by catechol-*O*-methyltransferase (COMT) in the liver, and arctiin and tracheloside existed as metabolite 1, the genuine genin, in the bloodstream (Nose et al. 1993). Three novel metabolites of arctigenin, namely, arctigenic acid, arctigenin-4′-*O*-glucuronide and 4-*O*-demethylarctigenin, were identified after oral administration of arctigenin in rats (Gao et al. 2013). Another potential metabolite of arctigenin, arctigenin-4′-*O*-sulfate, was identified in-vitro but not in-vivo. Rapid hydrolysis in plasma was identified as the major metabolic pathway of arctigenin after its oral administration and paraoxonase 1 was confirmed to be the enzyme responsible for arctigenin hydrolysis.

Three metabolites of arctiin were isolated and identified in rat faeces as (−)-enterolactone, (−)-arctigeninand[(2*R*,3*R*)-2-(3′-hydroxybenzyl)-3-(3″,4″-dimethoxybenzyl)-butyrolactone] (Wang et al. 2013). Arctiin was excreted 19.84 % in urine and 1.80 % in faeces, respectively; enterolactone, the abundant main metabolite, was excreted 35.80 % in faeces.

Toxicity Studies/Issues

A case of a 26-year-old woman complaining of blurred vision, inability to void, a dry mouth and a history of bizarre behaviour after ingestion of a commercial preparation of burdock tea was reported by Bryson et al. (1978). A case of anticholinergic poisoning associated with the consumption of a commercial burdock root tea preparation was confirmed by laboratory analysis in Arizona (Rhoads et al. 1984). The patient experienced mild anticholinergic symptoms which were caused by an atropine contaminant in the commercial preparation.

Studies had demonstrated that inulin-type fructans, when administered in the diet at high levels, do not result in mortality, morbidity, target organ toxicity, reproductive or developmental toxicity or carcinogenicity (Carabin and Flamm 1999). Several in-vitro studies had also shown the absence of mutagenic or genotoxic potential. A series of clinical studies had been reported showing that up to 20 g/day of inulin and/or oligofructose to be well tolerated.

Treatment for 28 days with preparations of burdock did not affect the parameters of glucose homeostasis examined in normal mice (basal plasma glucose and insulin, glucose tolerance, insulin-induced hypoglycaemia and glycated haemoglobin) (Swanston-Flatt et al. 1989). Administration of burdock to streptozotocin-diabetic mice aggravated the diabetic condition.

Allergy and Burdock Ophthalmia Issues

Sasaki et al. (2003) reported a case of a 53-year-old Japanese man, with a history of developing urticaria (once after consuming mackerel and 10 times after consuming boiled burdock, carrot, curry and rice), who presented with redness over his entire body and dyspnea 1 hour after eating boiled burdock. The results of the skin prick tests were positive for raw and boiled burdock. Also, contact with the burdock plant could cause allergic contact dermatitis reaction (Rodriquez et al. 1995). Allergic skin reactions had also been reported with the use of burdock plasters on the skin.

Burdock burr contains minute pointed, barbed bracts that can cause painful and severe ocular discomfort, foreign body sensation, photophobia, marked conjunctival hyperaemia, stringy mucus or even pseudomembranous, conjunctival exudation, eyelid oedema, blepharospasm and pathognomonic abrasions of the cornel epithelium (Havener et al. 1955). They reported that a water-soluble glycoside irritant in burdock plant when injected caused severe conjunctival irritations similar to that caused by the embedded bract. Breed and Kuwabara (1966) reported that burdock bristles when embedded in the conjunctiva, or rarely in the cornea, may evoke a characteristic clinical picture of burdock ophthalmia as described by Havener et al. (1955).

Traditional Medicinal Uses

Burdock has been used therapeutically in Europe, North America and Asia for hundreds of years (Grieve 1971; Foster and Duke 1998; Duke and Ayensu 1985 Chan et al. 2011; Chevallier 1996). Burdock has been employed in traditional medicine to treat abscesses, joint pain, urinary complaints and respiratory ailments (congestion, fever caused by colds, flu and pneumonia) and to surmount serious health challenges by stimulating cellular regeneration, detoxification and cleansing. Burdock is one of the foremost detoxifying herbs in both Chinese and Western herbal medicines (Chevallier 1996). The herbal drug is listed in the German Pharmacopoeia for treating gastrointestinal disorders, as well as joint and bone ailments. The roots, seeds and leaves of burdock have been investigated in view of its popular uses in traditional Chinese medicine (TCM). The plant is antibacterial, antifungal and carminative (Launert 1981; Yeung 1985); has soothing, mucilaginous properties; and is employed for therapeutic treatment of many types of skin diseases, burns, bruises, herpes, eczema, acne, impetigo, ringworm, boils and bites (Grieve 1971; Phillip and Foy 1992). *Arctium lappa* has been reported to relieve gastrointestinal

symptoms (de Almeida et al. 2013) and used as a diuretic, depurative and digestive stimulant and in dermatological conditions (Dos Santos et al. 2008). Burdock is a traditional medicinal plant that is popularly used for treating hypertension, gout, hepatitis and other inflammatory disorders (Lee et al. 2012).

Dried burdock root of 1-year-old plants is the official medicinal herb, but the leaves and fruits have also been used (Grieve 1971). The roots are considered to be alterative, aperient, blood purifier, cholagogue, depurative, diaphoretic, diuretic and stomachic (Duke and Ayensu 1985; Foster and Duke 1998). Roots of burdock are used in folk medicine as a tincture, a decoction, an extract, an infusion and an oil for gout, rheumatism and several skin diseases and as a diuretic and pathogenic agent and are used topically for eczema, ulcers, skin eruptions, festering wounds, furunculosis, sciatica and radiculitis (Azizov et al. 2012). Burdock root has traditionally been recommended as an aphrodisiac agent (Cao et al. 2012). It is used to treat impotence and sterility in China, and Native Americans included the root in herbal preparations for women in labour. Dried burdock roots and burdock tea are considered to be a traditional blood purifier, a diaphoretic, an alterative and a diuretic. Burdock root is used to treat conditions caused by an 'overload' of toxins, such as throat and other infections, boils, rashes and other skin problems, and is thought to be particularly good at helping to eliminate heavy metals from the body (Chevallier 1996). Medicinal herbs (*Arctium lappa* roots, *Sophora japonica* fruits, *Acorus calamus* roots, *Urtica dioica* leaves, *Humulus lupulus* fruits) are promising remedies for the prevention and treatment of alopecia (Galkin et al. 2013). Burdock fruit is an often-used herbal drug in traditional Chinese medicine for the treatment of common cold caused by wind and heat (Sun et al. 1992). Burdock seed is alterative, antiphlogistic, depurative, diaphoretic and diuretic (Duke and Ayensu 1985). Burdock seeds, containing arctigenin and its glycoside arctiin as main constituents, have been used as a diuretic, an anti-inflammatory and a detoxifying agent in traditional Chinese medicine (Hyam et al. 2013) and are widely used as a TCM for dispelling wind and heat and are included in the Chinese Pharmacopoeia (Zhao et al. 2009). Burdock seed is used as an alternative medicine for the treatment of inflammatory disorders (Kim et al. 2008). The pulverised seed and leaves are poulticed onto bruises, burns, ulcers and sores (Foster and Duke 1998).

Other Uses

Zhang et al. (2013) found that burdock fructooligosaccharide (BFO) enhanced the biocontrol efficacy of *Rhodotorula mucilaginosa* in controlling postharvest decay of peaches.

Burdock has potential application for biogas production. The average biogas yield of 480 L/kg_{vos}, 520 L/kg_{vos} and 296 L/kg_{vos} was obtained from greater burdock, large-leaf lupin and Sosnovsky cow parsnip biomass, respectively (Dubrovskis et al. 2011). The average methane yield of 276, 322 and 226 was obtained from greater burdock, large-leaf lupin and Sosnovsky cow parsnip biomass, respectively. The estimated average energy potential per unit of area is 87 GJ/ha and 82 GJ/ha for greater burdock and large-leaf lupin biomass cultivated on unused agricultural land area, respectively, and the energy potential was 38 GJ/ha for Sosnovsky cow parsnip.

Comments

Flor-Essence – a proprietary natural health product – is a compound herbal product of eight herbs including burdock (Saleem et al. 2009). Sixteen markers could be identified in Flor-Essence originating from four contributing herbs including four caffeoylquinic acids; three dicaffeoylquinic acids; two caffeic acid derivatives from *Arctium lappa*, luteolin-7-*O*-glucoside and luteolin; five apigenin glycosides; and apigenin from *Rumex acetosella* and *Nasturtium officinale* and sissotrin from *Trifolium pratense*.

A North American herbal formula called Essiac is a proper treatment for cancer and consists of *Arctium lappa*, *Rumex acetosella*, *Ulmus rubra* and *Rheum palmatum* (Chevallier 1996).

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Helianthus tuberosus

Scientific Name

***Helianthus tuberosus* L.**

Synonyms

Helianthus esculentus Warsz., *Helianthus serotinus* Tausch, *Helianthus tomentosus* Michaux, *Helianthus tuberosus* var. *subcanescens* A. Gray

Family

Asteraceae

Common/English Names

Earth Apple, Canada Potato, Girasole, Jerusalem Artichoke, Jerusalem sunflower, Sunchoke, Sunflower Artichoke, Sunroot, Topinambur, Woodland Sunflower

Vernacular/Local Names

Arabic: Tartŭf, Tuffâhh El Ard
Brazil: Batata-Tupinambá, Girassol-De-Batata, Tupinambá, Tupinambor
Chinese: Ju Qian, Ju Yu
Czech: Slunečnice topinambur
Danish: Jordskok
Dutch: Aardaartisjok, Aardpeer, Topinamboer
Estonian: Maapim, Mugul-Artishokk, Mugul-päevalill, Näiteks Maapirn, Topinambur
Esperanto: Helianto tubera, Ter-piro
Finnish: Maa-Artisokka
French: Artichaut De Jérusalem, Artichaut De Terre, Artichaut Du Canada, Hélianthe Tubéreux, Navet De Jerusalem, Poire De Terre, Soleil Vivace, Topinambour, Truffe du Canada
German: Erdbirne, Jerusalem Artischoke, Knollensonnenblume, Ross-Erdapfel, Topinambur
Hungarian: Csicsóka
India: Suurajamuu (Hindi)
Italian: Carciofo Di Terra, Carciofo Di Gerusalemme, Elianto Tuberoso, Girasole Del Canada, Patata Del Canada, Rapa Tedesca, Tartufo Di Canna, Topinambur, Tupinambur
Japanese: Kiku Imo
Korean: Ttung Dahn Ji, Ttung Ttan Ji
Norwegian: Jordskokk
Polish: Słonecznik bulwiasty, Topinambur
Portuguese: Girassol-batateiro, Topinambo, Tupinambo
Russian: Topinambur, Podsolnečnik Klubenosnij, Zemljanaja Gruša
Slovaščina: Laška, Lashka Repa, Sončnica–laška repa, Topinambur
Slovencina: Slnečnica hľuznatá
Spanish: Aguaturma, Alcachofa De Jerusalém, Batata De Caña, Castańa De Tierra, Girasol

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Tuberosa, Papa Alcachofa De Jerusalem, Papa De Jerusalem, Pataca, Patata De Cańa, Patata De Judea, Topinambur Tupinambo
Swedish: Jordärtskocka
Thai: Thantawan-Hua
Turkish: Beyaz Yer Elmasi, Tavuk Gökü, Yer Elması, Yerelmasi, Yerelması, Yildizkökü
Vietnamese: Cúc Vu
Welsh: Artisiog Jerwsalem

Origin/Distribution

Jerusalem artichoke is an ancient Amerindian native to eastern North America from Maine west to Dakota and southwards to northern Florida and Texas. It is now widely cultivated in many places around the world, including North America, France, Italy, Germany, East European countries, China and also (in spite of low suitability) in some tropical countries in the cooler highlands (India, Indonesia, Malaysia, Kenya, Zaire and Nigeria).

Agroecology

Although a temperate species, *H. tuberosus* tolerates sub-zero to hot temperatures (Duke 1983). Most Jerusalem artichoke cultivars require average annual temperatures of between 6 and 26 °C, within a growing season of at least 125 frost-free days (Cosgrove et al. 2000; Duke 1983). Jerusalem artichoke grows under different pedoclimatic conditions and shows good tolerance to frost, drought and other adverse conditions, as well as resistance to pests and diseases (Slimestad et al. 2010). *H. tuberosus* tubers can withstand freezing for months even if the frost kills the stems and leaves (Duke 1983).

Jerusalem artichoke tolerates annual precipitation in the range of 310–2,820 mm (Duke 1983). However, an evenly distributed rainfall of up to 1,250 mm is preferred for optimal growth. The crop is tolerant of drought and survives short periods of flooding. Its water use efficiency is estimated to be between 1.1 and 1.9 g dm/L of water transpired (Conde et al. 1991). When only 50 % of the water requirement was available, tuber yield of Jerusalem artichoke was reduced by 20 % (Conde et al. 1991). Severe or mild water stress was reported to cause significant tuber yield losses of Jerusalem artichoke grown on a sandy loam soil (Schittenhelm 1999). Monti et al. (2005) found that the time course of Jerusalem artichoke plant growth and biomass partitioning was significantly affected by water availability especially during the period of the two first irrigations. *H. tuberosus* is generally considered to be moderately tolerant to salinity and to exhibit genotypic variability in salinity tolerance (Long et al. 2008; Newton et al. 1991), so they could be safely grown in salt-affected land with 25 and 50 % seawater irrigation (Zhao et al. 2008). Studies by Zhao et al (2008) showed that Jerusalem artichoke could be safely grown in salt-affected land of Laizhou area in North China Plain with 25 and 50 % seawater irrigation. Irrigation treatment with 75 %, 25 % and 50 % seawater increased the yields of Jerusalem artichoke compared to nonirrigated control. Long et al. (2008) found that 10 % seawater stress treatment had the least effect on Jerusalem artichoke plant growth, while at 25 % seawater growth was significantly inhibited. Addition of nitrogen ameliorated the toxicity of seawater by improving the antioxidative enzymes, enhancing leaf proline and soluble sugars and altering the distribution of inorganic ions in *H. tuberosus*. Studies by Long et al. (2010) found great variability for seawater tolerance among *H. tuberosus* varieties and that greater photosynthesis capacity, higher relative growth rate and relatively higher tissue Na^+ accumulation at high seawater concentrations appear to be associated with seawater tolerance in *H. tuberosus* varieties.

Jerusalem artichoke thrives in a wide range of soil types and pH levels, but production is favoured by slightly alkaline soils with optimal pH in the range of 4.5–8.6 (Duke 1983; Kosaric et al. 1984). It does best in friable, moderately well-drained soil in full sun to partial shade. Clay soils that are prone to waterlogging, for instance, may become too acid for optimum tuber growth. Greenhouse and field trials on heavy clay loam conducted by Newton et al. (1991) found that soil salinity reduced growth (plant biomass) and tuber biomass of Jerusalem artichoke.

Substantial genetic variation in the date and the duration of flowering were found with the onset of flowering ranging from 69 to 174 days after planting (DAP). Flowering duration ranged from 21 to 126 days (Kays and Kulture 2005). The onset of flowering was substantially affected by the planting date and to a lesser extent by the location. Studies have established critical day lengths for Jerusalem artichoke, although a wide variation has been observed between different clones. *H. tuberosus* requires short days for flowering, and the critical day length for a range of clones was found to be between 13 and 13.5 hours (Allard and Garner 1940; Zhao et al. 1984). *H. tuberosus* requires longer periods of light from seedling to maturation and shorter periods for tuber formation in late summer, as they are sensitive to day length hours (Huxley et al. 1992). But they do not grow where day lengths vary little (Duke 1983).

Edible Plant Parts and Uses

The edible artichoke tuber has a sweet nutty taste and is used as a vegetable that could be baked, steamed and mashed, or made into soups, sauces or pickles or eaten raw in salads. They are especially good grated into fresh salads and are a perfect snack for dieters. Boiled and mashed, they are rather similar to potatoes and can be used like potatoes in most recipes and can be made into a delicious and nutritious soup. Jerusalem artichokes also make delicious French fries. They are excellent pickled. Jerusalem artichokes can be roasted like potatoes with fowl or meat or bake with cream and cheese for a delicious scalloped/au gratin. The roasted tubers are used as a coffee substitute (Facciola 1990). The tubers can also be used for the production of alcohol and fructans.

H. tuberosus tubers being rich in inulin are an important source of fructose for industry. They can be used to make sweetening and inulin-rich floury products (Izsaki 2006). Due to the presence of inulin, starch which cannot be digested by the human enzyme system and being a good source of dietary fibres, the tubers provide food bulk without the associated calories. Compared to standard and substituted bread, Jerusalem artichoke bread prepared from tuber powder showed a high quality in organoleptic evaluation (grade I with 36.5 and 37.5 scores) (Praznik et al. 2002). Cakes made with 5–10 % Jerusalem artichoke tuber powder (JAP) contained 10.4 and 23.7 mg inulin/g dm, respectively (Celik et al. 2013). Panellists liked the crumb cell structure, flavour, chewiness, softness and sweetness of cakes with Jerusalem artichoke powder equally. Thus, with JAP can be used as a natural source of inulin in many bakery products such as breads, pastas, biscuits and cakes. The consumption of the bakery products containing JAP may help to increase the daily intake of inulin, a health-beneficial constituent for human nutrition. Studies by Kronberga et al. (2013) found that it was possible to substitute 40 % of total amount of sugar with Jerusalem artichoke syrup and so increase the nutritional value of marmalades and cakes and prolong their shelf life. Dried chips containing inulin, other dietary fibres and a small amount of polyphenol can be prepared from Jerusalem artichoke tuber (Takeuchi and Nagashima 2011). Dried tubers had considerable water-holding capacity at low temperatures and viscosity-lowering activity on potato starch paste while heating. Their results suggested that Jerusalem artichoke tubers could be more widely utilised in the food industry as a functional modifier of other materials.

Gedrovica et al. (2011) reported that increasing the content of Jerusalem artichoke powder in pastry products like cakes, honey biscuits and butter biscuits substantially increased the content of non-starch polysaccharides. Non-starch polysaccharides (soluble and insoluble) constitute the main part of dietary fibre. They reported Jerusalem artichoke to be a good source of non-starch polysaccharides/dietary fibre as it is rich in fibre, vitamins, minerals and fructans.

Knowledge on the quality of raw and boiled Jerusalem artichoke tubers can be used to inform consumers on the right choice of raw material and thereby increase the consumption of the vegetable (Bach et al. 2013). The appropriateness of raw Jerusalem artichoke tubers was related to Jerusalem artichoke flavour, green nut flavour, sweetness and colour intensity, whereas the

appropriateness of boiled tubers was related to celeriac aroma, sweet aroma, sweetness and colour intensity. Earlier Bach et al. (2012) found significant differences between harvest times and Jerusalem artichoke varieties for sensory scores and concentrations of tuber aroma volatiles. The total concentration of sampled volatiles was low with an average of 25.4 ng/g fresh weight and consisted mainly of terpenes. The sensory quality was determined by quantitative descriptive analysis of 19 sensory attributes. The sensory and aroma results separated the red-skinned variety Rema from the white-skinned Mari and Draga. Rema had a higher content of terpenes and was more associated with the unpleasant attributes iron flavour, fungus/earthy aroma and dried nut flavour compared to Mari and Draga.

A high-quality fructose syrup can be produced from Jerusalem artichoke tubers (Fleming and GrootWassink 1979). They reported that Jerusalem artichoke had the potential to produce more sugar per acre than corn or sugar beets.

Plate 1 Jerusalem artichoke stem tuber

Plate 2 Tuber with eyes, node and internode

Plate 3 Close view of tuber

Botany

A multibranched herbaceous perennial growing to 1.5–3 m high and producing rhizomatous subterranean stem tubers and fibrous roots. Tubers knobby, uneven, white, red or purple skinned, ranging in size from 7.5 to 10 cm long, 3–5 cm thick, with nodes, internodes and eyes, the flesh is white (Plates 1, 2 and 3). The stems are erect, scabro-hispid to hirsute. Leaves mostly cauline opposite or alternate proximally. Lower leaves are larger, broadly ovoid–acute, up to 30 cm long, upper ones smaller and narrower, alternate and borne on winged petioles, 2–8 cm. Lamina 3-nerved from near bases, lanceolate to ovate, 10–23 × 7–15 cm, bases broadly to narrowly cuneate, margins entire or serrate, abaxial faces finely hairy and gland-dotted, adaxial scabrous. Flowering heads 5–7.5 cm across, 5–15, terminal on the branches. Involucres hemispheric. Phyllaries dark green, 22–35, bases appressed, apices more or less spreading, sometimes reflexed in fruit, lanceolate. Ray florets 10–20; laminae 25–40 mm. Disc florets 60 or more; corollas 6–7 mm, lobes yellow; anthers dark brown or black, appendages dark or yellowish. Cypselae 5–7 mm, glabrous or distally hairy; pappi with 2 aristate scales and 0–1 deltoid scales.

Nutritive/Medicinal Properties

Tuber Nutrients/Phytochemicals

Wild and cultivated Jerusalem artichoke genotypes appear to contain adequate protein and macro- and micro-minerals to contribute significantly towards a nutritionally balanced diet (Seiler 1990).

Jerusalem artichoke tubers were reported to contain mainly water-soluble polysaccharides (WSPS) (12.3 %), pectic substances (PS) (1.6 %), hemicelluloses (HMC)-A (1.2 %), HMC-B (0.8 %) and proteins (Rakhimov et al. 2003, 2011). WSPS comprised of glucose, fructose, saccharose, kestose and a homologous series of D-fructofuranosides (9.3 %), each member of which corresponded to the empirical formula Glcp 1→2Fruf1-[2Fruf1]n. The homologous series of fructosans starts at the saccharose of the lowest homolog (for $n=0$) followed by the trisaccharide kestose and then tetrasaccharide w. Each oligofructoside differs from the previous one by a fructose unit. The highest homolog of this series is inulin. Pectin was found to consist of galactose, glucose, rhamnose, arabinose and galacturonic acid units forming the main chain. Glucose, galactose, xylose, arabinose and traces of rhamnose and galacturonic acid were detected in the hemicellulose hydrolysate. The tuber contained 0.86 % (per dry mass) nitrogen or 5.45 % protein content calculated by the Kjeldahl method. The amino acid composition of the protein determined after acid hydrolysis included asparagine 1.41 %, threonine 1.26 %, serine 1.27 %, glutamine 2.94 %, proline 2.01 %, glycine 0.96 %, alanine 0.97 %, 1/2 cysteine 1.63 %, valine 1.30 %, methionine 1.80 %, isoleucine 1.83 %, leucine 2.91 %, tyrosine 3.07 %, phenylalanine 2.18 %, histidine 1.34 %, lysine 2.51 % and arginine 1.8 %. Thus the chemical composition of Jerusalem artichoke tubers included monosaccharides, fructooligosaccharides, inulin, hemicelluloses, pectinic substance and proteins. Syrup prepared from tuber juice contained at least 71 % dry solids, protein content 5.45 % and inulin content 26 % with pH 3–4.5 and density 1.35–1.36 (Rakhimov et al. 2011). Total nitrogen of 114 Jerusalem artichoke populations varied from 0.695 to 2.179 % dry weight (mean 1.23 %), alpha amino nitrogen content 0.012–0.118 % fresh weight (mean 0.07 %), potassium 0.231–0.452 % fresh weight (mean 0.403 %) and sodium 0.0003–0.0143 % fresh weight (mean 0.007 %) (Terzic and Atlagic 2009). The following attributes of Jerusalem artichoke tubers impart nutritional and health benefits: presence of alpha amino nitrogen, an essential nutrient for animals; a protein content similar to potato; high K/Na ratio that can positively affect the reduction of Na/K ratio and lower systolic blood pressure by a significant amount in adults with mild hypertension, high inulin content up to 80 % of the total sugar content as a dietary fibre and a fructose polymer that positively influences digestion and sugar blood levels (Terzic and Atlagic 2009).

In another analysis, proximate nutrient value of raw Jerusalem artichoke per 100 g edible portion was reported as water 78.01 g, energy 73kcla (304 kJ), protein 2 g, fat 0.01 g, ash 2.54 g, carbohydrate 17.44 g, total dietary fibre 1.6 g, total sugars 9.60 g, Ca 14 mg, Fe 3.40 mg, Mg 17 mg, P 78 mg, K 429 mg, Na 4 mg, Zn 0.12 mg, Cu 0.140 mg, Mn 10.0 mg, Se 0.7 μg, vitamin C 4 mg, thiamine 0.2 mg, riboflavin 0.06 mg, niacin 1.3 mg, pantothenic acid 0.397 mg, vitamin B6 0.077 mg, total folate 13 μg, total choline 30 mg, vitamin A (RAE) 1 μg, vitamin A 20 IU, β-carotene 12 μg, vitamin E (α-tocopherol 0.19 mg), vitamin K (phylloquinone) 0.1 μg, total monounsaturated fatty acids 0.004 g, 18:1 undifferentiated 0.004 g, total polyunsaturated fatty acids 0.001 g and 18:2 undifferentiated 0.001 g (USDA-ARS 2014). Jerusalem artichoke tubers, on a dry basis, yielded approximately 76 % soluble sugars (combined fractions from the drain liquor and hot water extract of skinless tubers and skins) and the remaining 24 % as an insoluble residue (Mullin et al. 1994). On a dry weight basis, the residues contained 20–25 % protein which was double the concentration in the soluble extract; the residues also contained up to 43 % total dietary fibre. Soluble sugars ranged over 75–85 % of the dry matter in the hot water extracts, which was double the amount retained

in the residue. The lowest ash content (3.2–4.9 %) was found in the skinless tubers residue, and the highest (5.9–7.5) was in the skin residue. Tubers of *H. tuberosus* Rote Zonenkugel variety was found to contain high-protein content (6.3 %), four times higher content of sulphur amino acids and over 2 times higher content of all essential amino acids in comparison to their contents in chicory and potato (Cieślik et al. 2011). The essential amino acids in *H. tuberosus* tuber (mg/100 g) were histidine 17 mg, isoleucine 29 mg, leucine 40, lysine 45, methionine +cystine 23 mg, phenylalanine +tyrosine 44 mg, threonine 29 mg and valine 33 mg. Potassium (21,615–26,251 mg/kg), phosphorus (2,585–4,791 mg/kg), calcium (1,573–2,073 mg/kg) and magnesium contents were found at high levels in Jerusalem artichoke tubers growing in Konya provinces in Turkey (Harmankaya et al. 2012). Zinc content ranged from 11 to 15.6 mg/kg, iron 23.32–54.46 mg/kg, copper 4.50–8.98 mg/kg and chromium 0.396–0.642 mg/kg. Ash content ranged from 5.7 to 7.63 % and protein content at 6.23–10.71 %.

Uridine diphosphate fructose was isolated in a pure state from the acid-soluble extracts of Jerusalem artichoke tubers (Umemura et al. 1967). The yield was 1.3 μmoles from 10 kg of peeled tubers. In activated *H. tuberosus* tuber tissues, citrulline was found to be a direct or indirect (via arginine) precursor of putrescine (Speranza and Bagni 1978).

Lipid composition of Jerusalem artichoke tubers was reported as lipids 1.7 %, moisture and volatiles 34.8 %, acid number 4.0 mg KOH, total carotenoids traces, fatty acids after saponification 47.1 %, unsaponifiable substances 15.2 %, neutral lipids 49.6 %, glucolipids 43.1 % and phospholipids 7.3 % (Talipova 2001). Neutral lipids comprised hydrocarbons, carotenoids, fatty acid esters with phytosterols and triterpenols, triacylglycerines, free fatty acids, triterpenols, 4-monomethylsterols, sterols and chlorophylls. Glucolipids contained mono- and digalactosyldiacylglycerines, sterolglycosides and their fatty acid esters. Phospholipids comprised phosphatidylethanolamines, phosphatidylcholines, phosphatidylinosites and phosphatide acids. The fatty composition of the tubers was reported as total saturated fatty acids 32.4 %, 12:0 (lauric acid) 0.1 %, 14:0 (myristic acid) 0.45 %, 16:0 (palmitic acid) 30.3 %, 18:0 (stearic acid) 1.6 %, total unsaturated fatty acids 67.6 %, 18:1 (oleic acid) 1.2 %, 18:2 (linoleic acid) 54.5 % and 18:3 (linolenic acid) 32.4 % (Talipova 2001).

The amount of lipids extracted from the tubers were as follows: total lipids (0.56 %), free lipids (0.39 %) and bound lipids (0.36 %) (Chernenko et al. 2008). Total lipid was light yellow and contained carotenoid pigments (34.7 mg %). Bound lipids comprised neutral lipids (29.9 %), glucolipids (46.9 %) and phospholipids (23.2 %). Free lipids comprised mainly of neutral lipids. The following classes of neutral lipids were found: paraffinic and olefinic hydrocarbons, isoprenoid hydrocarbon squalene, tocopherols, triacylglycerides, free fatty acids, isoprenoid alcohols, triterpenols and sterols. Among the phospholipids, phosphatidylinositols (PI), phosphatidylcholines (PC), phosphatidylethanolamines (PE), phosphatidylglycerines (PG) and phosphatidic acid were identified. The main glucolipids were sterolglycosides and digalactosyldiglycerides; others included sulfolipids, cerebrosides and monogalactosyldiglycerides. The qualitative composition of the fatty acids in all lipid classes was the same and consisted of ten acids. However, they differed significantly quantitatively. The 18:0 and 16:0 acids dominated the saturated acids from polar lipids. The neutral lipids isolated from bound lipids contained a large amount of linoleic acid (53.0 %) and small amounts of 12:0, 13:0, and 14:0 acids. The total amount of unsaturated fatty acids in them was greater than 70 %. From total lipids, 5.2 % of unsaponified substances were isolated containing 46.9 mg% carotenoids. The unsaponified component comprised 17.9 % isoprenols and triterpenols, 13.2 % sterols, 8.2 % hydrocarbons, 9.6 % triterpenols, 19.4 % unidentified component I and 31.5 % unidentified component II.

Many studies had reported Jerusalem artichoke tubers to be rich in inulin. The nutritional energy value of inulin was reported to be lower than that of sucrose, being in the range 4.2–6.3 kJ/g (Roberfroid et al. 1993). Jerusalem artichoke tubers were reported to have 162.4 mg/g dm

inulin content (Celik et al. 2013). Inulin is a generic term to cover all β (2→1) linear fructans including native inulin (DP 2–60, DP (av) = 12), oligofructose (DP 2–8, DP (av) = 4) and inulin HP (DP 10–60, DP (av) = 25) as well as Synergy 1, a specific combination of oligofructose and inulin HP (Roberfroid 2005, 2007). Inulin-type fructans are prebiotic dietary fibres and classified as 'non-digestible' carbohydrates as they resist hydrolysis by intestinal digestive enzymes and are also functional food ingredients. They are also low-calorie carbohydrates [6.3 kJ/g (1.5 kcal/g)]. By increasing faecal biomass and water content of the stools, they improve bowel habits. They affect gastrointestinal functions not because of their physicochemical properties but rather because of their biochemical and physiological attributes. Fermentation of inulin-type fructans in the large bowel preferentially stimulate the proliferation of *Bifidobacteria* (and possibly a few other genera), thus causing significant changes in the composition of the gut microflora by increasing the number of potentially health-promoting bacteria and reducing the number of potentially harmful species. They also induce changes in colonic epithelium stimulating proliferation in the crypts, increasing the concentration of polyamines, changing the profile of mucins and modulating endocrine as well as immune functions. The claim 'inulin-type fructans enhance calcium and magnesium absorption' had been scientifically substantiated, and the most active product was oligofructose-enriched inulin (Synergy 1) (Roberfroid 2007). A series of studies had demonstrated that inulin-type fructans modulated the secretion of gastrointestinal peptides involved in appetite regulation as well as lipid metabolism. Studies had also been reported that inulin-type fructans reduced the risk of colon carcinogenesis and improved the management of inflammatory bowel diseases.

All the fructans (inulin) with a DP ≥3 (i.e. the trisaccharide isokestose and larger polymers of fructose) were found to be located exclusively in the vacuoles of protoplast of *H. tuberosus* tubers, while sucrose, glucose and fructose were located only partially there (Frehner et al. 1984). The vacuoles were also found to be the sole cell compartments containing fructan-synthesising enzyme activities (sucrose–sucrose–fructosyltransferase and fructan–fructan–fructosyltransferase) and fructan-degrading enzyme activity (fructan exohydrolase), depending on the stage of development of the tubers. Two key enzymes in inulin metabolism identified in *H. tuberosus* were sucrose–sucrose 1-fructosyltransferase (SST), the enzyme for initiating inulin synthesis leading to 1-kestose, and fructan-1-fructosyl-transferase (FFT) leading to higher inulin polymers (Edelman and Jefford 1968). The enzyme sucrose–sucrose 1F-β-D-fructosyl-transferase involved in fructan synthesis was isolated from *H. tuberosus* tubers (Praznik et al. 1990). Sucrose–sucrose 1-fructosyltransferase (1-SST), an enzyme involved in fructan biosynthesis, was purified to homogeneity from *Helianthus tuberosus* tubers (Koops and Jonker 1994). 1-SST preferentially catalysed the conversion of sucrose into the trisaccharide 1-kestose (GF2). Other reactions catalysed by 1-SST at a lower rate were self-transfructosylations with GF2 and 1,1-nystose (GF3) as substrates yielding GF3 and 1,1,1-fructosylnystose (GF4), respectively, as products. 1-SST also catalysed the removal of the terminal fructosyl unit from both GF2 and GF3, which resulted in the release of sucrose and GF2, respectively, and free fructose. Sucrose–sucrose 1-fructosyltransferase (1-SST) was purified 100-fold from tubers of *Helianthus tuberosus* L. and could be separated by isoelectric focusing into five isoforms which all were composed of two subunits (59 and 26 kDa) (Lüscher et al. 1996). When a combination of 1-SST and with fructan–fructan 1-fructosyltransferase (1-FFT) was incubated with sucrose, a series of oligofructosides with a degree of polymerisation of up to 20 was formed. Amino acid sequences of tryptic peptide fragments from both 1-SST and 1-FFT indicated these enzymes to be highly homologous with plant invertases.

The fructan-β-fructosidase activity (1-FEH) that degrades inulin in tubers of *Helianthus tuberosus* L. appeared to be developmentally regulated; it was low in growing tubers but increased during dormancy and sprouting (Marx et al. 1997). The enzyme exhibited a high substrate

specificity, hydrolysing terminal β-(2–1)-fructosyl-fructose linkages in linear and branched fructan oligomers; β-(2–6) linkages were hardly hydrolysed. Hydrolysis of inulin oligomers followed normal saturation kinetics: K_m values for 1,1-kestotetraose and 1,1,1-kestopentaose were 8–3 mM and 12 mM, respectively. Fructosyl residues were hydrolysed from inulin oligomers by a multichain mechanism. The fructan-β-fructosidase showed optimal enzyme activity at pH 5–2, and it retained its full activity after preincubation for 1 hour at up to 40 °C.

Spring-harvested Jerusalem artichoke tubers containing low molecular weight inulin were found to be well suited for fermentations or for the isolation of inulooligosaccharides. Tubers not exposed to frost and containing high molecular weight inulin were better sources for the production of high-fructose syrup (Praznik and Beck 1987). Inulin content in *H. tuberosus* tubers decreased during storage (Cabezas et al. 2002). The fructan fraction having molecular weight between 800 and 1,200 increased after sucrose reached its maximum content [1.3–10^{-1} g/g DW] in tubers stored at 4 °C. Tuber maturity contributed to changes in inulin characteristics (Saengthongpinit and Sajjaanantakul 2005). A decrease in the more polymerised fractions (degree of polymerisation, DP >10) with an increase in fructose and sucrose composition was observed for late-harvested (20 weeks) tubers. For inulin DP 11–20, there was a decrease from 29.19 % at 16 weeks maturity to 26.71 % at 20 weeks maturity. For inulin DP 21–30, there was a decrease from 10.24 % at 16 weeks maturity to 9.52 % at 20 weeks maturity. For inulin DP >30, there was a decrease from 4.79 % at 16 weeks maturity to 4.48 % at 20 weeks maturity. There was no significant difference in inulin DP 3–10 when tubers were harvested at 16 weeks (47.01 %), 18 weeks (47.15 %) or 20 weeks (47.28 %) maturity. Sucrose increased from 7.51 % at 16 weeks maturity to 8.76 % at 20 weeks, while fructose increased from 7.51 to 8.76 % at 20 weeks maturity. Conversely, glucose decreased from 0.96 % at 16 weeks to 0.26 % at 20 weeks maturity. The inulin DP distribution profile from tubers, stored at 2 and 5 °C, significantly changed with increased storage time and temperature. Sucrose and DP 3–10 fractions increased, while DP >10 decreased, particularly after 4–6 weeks of storage. Changes in inulin composition were reflected by formation of a second fructan series DP 2′–DP 5′ during cold storage but not under frozen storage at −18 °C. These second fructan series had been found in trace amounts in fresh tubers by Ernst et al. (1996). They were characterised as inulo-n-ose that contained only β (2→1)-linked fructose molecules without an end glucose moiety (Ernst et al. 1996). These inulo-*n*-ose products, for example, 2′ for inulo-*bi-ose* and 3′ for inulo-t*ri*-ose, might be derived from large inulin molecules by hydrolysis of terminal glucose or fructose molecules. Saengthongpinit and Sajjaanantakul (2005) obtained peaks that corresponded to inulo-*n*-ose fructan, where inulo-*tri*-ose (3′) and inulo-*tetra*-ose (4′) were predominantly found after 2 weeks of tuber storage at 2 and 5 °C. Inulo-n-ose (5′) up to DP 17′ increased as a percentage with longer storage time. Tubers in frozen storage at −18 °C maintained their inulin DP distribution profiles.

Of the harvesting methods (i.e. stalk, tuber and 'integral crop'), the integral crop (stalks and tubers) of Jerusalem artichoke at flowering time showed the highest yield potential of total sugars (fructose+glucose) and inulin (18.6 and 17.9 t/ha, respectively) (Baldini et al. 2004). This was obtained by the clone Violette de Rennes, which also had the greatest inulin chain (DP) length. The average inulin chain length (DP) was highest at flowering time in both stalks and tubers with a range of 7.5–11.2 in the genotypes studied, while, at the final harvest of tubers, it significantly decreased reaching values ranging from 4.8 to 6.7. Among the organs analysed, the tubers at stalk harvest showed both the highest inulin content and the longest inulin chain, expressed as DP. As a result of overwintering, the amount of inulin was found to decrease in Jerusalem artichoke tubers due to its conversion to sucrose and the formation of inulin with a lower degree of polymerisation (Clausen et al. 2012). Major effects on the concentration of citric acid, malic acid, γ-aminobutyric acid (GABA) and adenosine

were also found. Malic acid concentration increased and citric acid concentration decreased. These changes, together with an increase in sucrose and GABA concentrations, were ascribed to mobilisation of nutrients prior to sprouting, suggesting that malic acid and GABA serve as carbon and nitrogen sources during sprouting of Jerusalem artichokes.

For the ten genetic variants of *H. tuberosus* collected and tested from different locations in Norway, 30–54 % of total carbohydrates were fructooligosaccharides, and the rest were sugars (mainly sucrose and low levels of fructose) (Seljåsen and Slimestad 2007). The level of total fructooligosaccharides varied from 20 mg/g (FW) for the variety 'Bergly' to 40 mg/g for 'Kirkeøy'. Kestose and Nystose were the abundant fructooligosaccharides in all cultivars. Tuber peels contained relatively high levels of total phenolics (39–129 mg GAE/100 g FW). Early Jerusalem artichoke variants gave the highest tuber yield (28.7 t/hour) and 1.72 kg tubers/plant (e.g. white Tysnes) under Norwegian growing conditions. Late variants gave highest aboveground biomass (Slimestad et al. 2010). The content of soluble carbohydrates was found to be highest in stalks in August (sucrose and fructooligosaccharides).

Jerusalem artichoke samples contained one major component (β-bisabolene, 2.62 μg/kg, 51 %) and a range of saturated long-chain hydrocarbons (22 %) (Macleod et al. 1982). B-farnesene (0.13 μg/kg) was also identified. β-Bisabolene because of its high concentration may contribute appreciably to the characteristic flavour of Jerusalem artichoke, although it did not possess an aroma characteristic of Jerusalem artichoke. Twenty-two phenolic compound were identified and quantified (100 g tuber or skin DW) from different Jerusalem artichoke varieties (Tchoné et al. 2007): gallic acid (1–140 mg), protocatechuic acid (5–200 mg), esculin (4–270 mg), gentisic acid (30 mg–3 g), catechin (1–300 mg), 4-hydroxybenzoic acid (1–90 mg), chlorogenic acid (20 mg–5 g), vanillic acid (1–520 mg), syringic acid (1–40 mg), caffeic acid (1–240 mg), epicatechin (4–800 mg), 2-hydroxy-3–5-dinitrobenzoic acid (2–140 mg), umbelliferone (2–110 mg), scopoletin (1–80 mg), *p*-coumaric acid (1–40 mg), coumaric-3-carbon acid (1–40 mg), ferulic acid (1–40 mg), sinapic acid (1–60 mg), 3-hydroxycinnamic acid (trace), ellagic acid (2–40 mg), 4-hydroxycoumarin (4–300 mg) and salicylic acid (30 mg–7 g).

Seven phenolic compounds, namely, 3-*O*-caffeoylquinic acid (chlorogenic acid), 5-*O*-caffeoylquinic acid (neo-chlorogenic acid), 4-*O*-caffeoylquinic acid (cryptochlorogenic acid), 3,5-*O*-dicaffeoylquinic acid, 3,4-*O*-dicaffeoylquinic acid, 4,5-*O*-dicaffeoylquinic acid and 1,3-*O*-dicaffeoylquinic acid were identified from two polish cultivars of Jerusalem artichoke tubers: Rubik and Albik (Kapusta et al. 2013). Albik had a phenolic acids content 18 % lower than Rubik. In relation to the dry matter, Rubik contained 1.7 g/kg and Albik 1.4 g/kg of total phenolics. The following phenolic compounds were quantified in the tubers of two cultivars Rubik and Albik (mg/kg DM), respectively: 3-*O*-caffeoylquinic acid (471.85 mg; 368.15 mg); 5-*O*-caffeoylquinic acid (59.05 mg; 30.36 mg); 4-*O*-caffeoylquinic acid (61.09 mg;61.65 mg); 3,5-*O*-dicaffeoylquinic acid (102.28 mg; 170.94 mg); 3,4-*O*-dicaffeoylquinic acid (630.39 mg;513.38 mg);4,5-*O*-dicaffeoylquinic acid (68.98 mg; 37.75 mg) and 1,3-*O*-dicaffeoylquinic acid (274.40 mg; 270.23 mg). The 3,4-*O*-dicaffeoylquinic acid was most abundant in both cultivars followed by 3-*O*-caffeoylquinic acid (chlorogenic acid) and then 1,3-*O*-dicaffeoylquinic acid.

Phytosterols were isolated and purified from Jerusalem artichoke tissues grown in-vitro in the presence of sodium acetate 1-^{14}C in the dark and under far red light (Hartmann et al. 1972). A reproducible increase of the specific radioactivity of sterols was observed for tissues subjected to far red light. Solubilisation of chromatin from Jerusalem artichoke tubers in 2,4-dichlorophenoxyacetic acid (2,4-D) solution was associated with dissociation of the DNA and associated histone and non-histone proteins (Yajima et al. 1975). Injection of d-[U-^{14}C] fructose into developing Jerusalem artichoke tubers produced labelled glucose 6-phosphate, fructose 6-phosphate, fructose 1,6-bisphosphate, fructans and fructose 1-phosphate (Morgan and Pridham 1985). The latter ester was

not produced on loading tubers with [U-^{14}C] sucrose. In contrast to the other hexose phosphates, fructose 1-phosphate did not appear to be metabolised.

Solubilisation of acid invertase associated with cell wall preparations from aged slices of Jerusalem artichoke tuber tissue was achieved with buffer of high ionic strength (Little and Edelman 1973). Wounding induced cinnamic acid hydroxylase (CAH) in Jerusalem artichoke tuber (Benveniste et al. 1977). CAH, a multienzyme system localised on the endoplasmic reticulum, catalyses transformation of *trans*-cinnamic acid into *p*-hydroxy-cinnamic acid. The content of cytochrome b_5, already present in the dormant tuber, was markedly enhanced by wounding. Proteins that were able to stimulate the exchange of phospholipids between natural membranes (mitochondria and microsomal fractions) or between artificial (e.g. liposomes) and natural membranes were isolated from cytosols of Jerusalem artichoke plant tissues (Douady et al. 1978). A cyclic AMP phosphodiesterase was isolated from dormant tubers of Jerusalem artichoke (Giannattasio et al. 1974). The enzyme hydrolysed 3′,5′-cyclic AMP to 3′-AMP and 5′-AMP. A cyclic AMP-binding protein with molecular weight of circa 240,000 was purified from Jerusalem artichoke rhizome tissue (Giannattasio et al. 1979). The binding protein was devoid of the following activities: cyclic AMP phosphodiesterase, 5′-nucleotidase, adenosine deaminase and ATPase. Arginase [l-arginine amidinohydrolase] from Jerusalem artichoke tubers was shown to be more substrate specific than other plant and animal arginases and found to be very sensitive to competitive inhibition by indospicine, ornithine and citrulline (Wright et al. 1981). The AMP aminohydrolase enzyme was purified from particulate extracts of Jerusalem artichoke tubers (Le Floc'h and Lafleuriel 1983). Fractionation of phenolase enzyme from Jerusalem artichoke resulted in fractions with various specific activities, with an increase in activity of 160-fold for the first unbound enzymatic fraction and 18-fold for a fraction eluted with glycine buffer (Zawistowski et al. 1987). Polyphenol oxidase was purified from Jerusalem artichoke tubers and was found to be primarily an o-dihydroxyphenol oxidase with apparent K_m values of 1.9, 3.5 and 3.9 mM for chlorogenic acid, 4-methylcatechol and catechol, respectively (Zawistowski et al. 1988b). An acidic fraction of polyphenol oxidase was isolated purified from Jerusalem artichoke tubers (Zawistowski et al. 1988a). The pH optimum for its oxidation of chlorogenic acid, 4-methylcatechol and catechol was 6.0. Sucrose synthase (UDP-D-glucose–D-fructose 2-α-D-glucosyltransferase) occurred as an extravacuolar enzyme in *Helianthus tuberosus* tubers and as active sucrose transporter in the tonoplast and was reported to play an important role towards sucrose synthesis in the tissue (Keller et al. 1988). Also found was the vacuolar marker β-N-acetylglucosaminidase and extravacuolar marker NAD-malate dehydrogenase in the protoplast lysate. Diamine oxidase activity was found to be associated with protoplasts and mitochondria in *H. tuberosus* tuber (Scoccianti et al. 1991). Polyphenol oxidase (PPO) was purified from Jerusalem artichoke tuber skin and flesh and characterised (Ziyan and Pekyardimci 2003). Optimum pH values were 7.5 for skin PPO and 8.0 for flesh PPO with 50 mM catechol. The optimum temperatures for skin and flesh PPO were 25 °C and 30 °C, respectively, with catechol. Thermal inactivation data indicated that apparent activation energies with catechol substrate were 29.34 kcal/mol for skin PPO and 42.56 kcal/mol for flesh PPO.

Ketodiene oxylipin biosynthesis in Jerusalem artichoke tubers was found to be mediated by the lipoxygenase pathway (Chechetkin et al. 2004). Through this pathway (9*Z*,11*E*,13*S*)-13-hydroperoxy-9,11-octadecadienoic acid (13-HPOD) was reduced to corresponding 13-hydroxy acid (13-HOD), which was then dehydrogenated into ketodiene (9*Z*,11*E*,13*S*)-13-oxo-9,11-octadecadienoic acid (13-KOD). Dehydrogenation of 13-HOD into 13-KOD was not dependent on the presence of either NAD or NADP, but was strongly dependent on the presence of oxygen. The enzyme flavin dehydrogenase catalysed the dehydrogenation of (9*S*,10*E*,12*Z*)-9-hydroxy-10,12-octadecadienoic acid (9-HOD) as effectively as 13-HOD, while

α-ketol, (9*Z*)-12-oxo-13-hydroxy-9-octadecenoic acid and ricinoleic acid did not act as substrates for the dehydrogenase.

9*Z*- and 9*E*-dodecenoic acids were epoxidised by a microsome preparation from Jerusalem artichoke tuber to form *cis*- and *trans*-epoxydodecanoic acids, respectively (Fahlstadius 1991). Kauralexins A3, B2 and B3, 4-epicommunic acid and unknown C_{15}-acetylenic compound were found in *H. tuberosus* (Bohlmann et al. 1980). 7-hydroxylated coumarin phytoalexins like ayapin and scopoletin were excreted from sliced *H. tuberosus* tuber tissues (Cabello-Hurtado et al. 1998). They accumulated in response to treatment with chemical elicitors like $CuCl_2$ or sucrose, but not in response to $MnCl_2$.

Two mannose-/glucose-binding lectins designated HTA 1 (a monodimer 17 KDa) and HTA 11 (a heterodimer, 17 KDa and 18 KDa) were purified from *H. tuberosus* callus (Nakagawa et al. 1996). They exhibited strong hemagglutinating activity. Heltuba A, a mannose-binding lectin, was isolated from *H. tuberosus* tubers (Bourne et al. 1999). It shared the carbohydrate-binding site and beta-prism topology of its galactose-binding counterparts: jacalin and *Maclura pomifera* lectin. Heltuba was found to be a cytosolic, tetrameric protein composed of four identical subunits of 15.5 kDa and exhibited a preferential specificity towards oligomannosides (Van Damme et al. 1999). Another lectin (HTTL) with native molecular mass of 72 kDa and subunit molecular masses of 17 and 18.5 kDa was isolated from *Helianthus tuberosus* tubers (Suseelan et al. 2002). The lectin agglutinated both untreated and trypsin-treated rabbit erythrocytes and did not agglutinate human blood cells of groups A, B and O. The HTTL was mitogenic to mouse spleen (total) cells at 25 μg/ml concentration. The lectin showed characteristics different from those of the earlier reported *H. tuberosus* tuber lectins. *Helianthus tuberosus* agglutinin (HTA) was found to be predominantly expressed in tubers and very weakly expressed in stems, but not expressed at all in other tissues (Chang et al. 2006). Southern blotting analysis indicated that HTA was encoded by a multigene family. HTA showed haemagglutination ability and a higher carbohydrate-binding ability for mannose than other tested sugars. Trypsin inhibitory activity was detected in the crude extracts of induced *Escherichia coli* BL21 (DE3) expressing HTA and was further verified by trypsin inhibitory activity staining on native polyacrylamide gel.

A total of 195 constituents were identified in the hydrodistilled essential oil of Jerusalem artichoke tubers, representing 88.2 and 93.6 % of the oil compositions for Samples A and B, respectively (Radulović and Đorđević 2014). The main constituents identified were β-bisabolene (22.9–30.5 %), undecanal (0–12.7 %), α-pinene (7.6–0.8 %), kauran-16-ol (6.9–9.8 %), 2-pentylfuran (0.0–5.7 %) and (*E*)-tetradec-2-enal (0.0–4.9 %). Several rare compounds characteristic for *Helianthus* ssp. were also detected: helianthol A (2.1–1.9 %), dihydroeuparin (0.0–2.3 %), eupatorin (0.0–0.4 %), desmethoxyencecalin (traces – 0.2 %), desmethylencecalin (0.0–0.4 %) and an isomer of desmethylencecalin (0.0 %-traces).

Leaf Phytochemicals

The leaf protein extraction residue contained 12 % crude protein and 28 % crude fibre (Rawate et al. 1985). Leaves were reported to contain water-soluble polysaccharides (WSPS) 3.3 %, pectinic substances 9.1 %, soluble sugars in alcohol 11.4 % and hemicelluloses 14.7 % (Rakhimov et al. 2011). Lipid composition of Jerusalem artichoke leaves was reported as lipids 2.7 %, moisture and volatiles 70.5 %, acid number 7.5 mg KOH, chlorophyll a 28.6 mg/g, chlorophyll b 9.6 mg/g, total carotenoids 1.8 mg/g, fatty acids after saponification 37.1 %, unsaponifiable substances 19.9 %, neutral lipids 51.4 %, glucolipids 37.6 % and phospholipids 11.0 % (Talipova 2001). Neutral lipids comprised hydrocarbons, carotenoids, fatty acid esters with phytosterols and triterpenols, triacylglycerines, free fatty acids, triterpenols, 4-monomethylsterols, sterols and chlorophylls. Glucolipids contained mono- and digalactosyldiacylglycerines, sterolglycosides and their fatty acid esters. Phospholipids comprised phosphatidylethanolamines, phosphatidylcholines, phosphatidylinosites and phosphatide acids.

Leaves had higher content of phospholipids, while tuber had higher contents of glucolipids. The fatty composition of the leaves was reported as total saturated fatty acids 44.9 %, 12:0 (lauric acid) 0.71 %, 14:0 (myristic acid) 0.70 %, 16:0 (palmitic acid) 42.2 %, 18:0 (stearic acid) 1.3 %, total unsaturated fatty acids 55.1 %, 18:1 (oleic acid) 4.7 %, 18:2 (linoleic acid) 30.8 % and 18:3 (linolenic acid) 19.6 % (Talipova 2001). *Helianthus tuberosus* leaves were found to contain protein, amino acid, reducing sugar, organic acids, phenols and tannins, flavonoids, lactones, cardiac glycoside and lipids (Liu et al. 2007). Feruloylquinic acids, *p*-coumaroylquinic acids, chlorogenic acids, caffeoylquinic acids, diferuloylquinic acids and caffeoylshikimic acids were found in the leaves of *Rudbeckia hirta*, *Helianthus tuberosus*, *Carlina acaulis* and *Symphyotrichum novae-angliae* (Jaiswal et al. 2011).

Heliangen, a sesquiterpene lactone and plant growth regulator was isolated from the leaves (Morimoto et al. 1966). Two heliangolides, deacetylviguiestenin (tagitinin E) and erioflorin, were also isolated from the leaves (Morimoto and Oshio 1981). Yoshihara et al. (1992) isolated the following tuber-forming substances from the leaves: tuberonic acid, methyl tuberonate glucoside, jasmonic acid, β-D-glucopyranosyltuberonic acid and six acetylene compounds including methyl 3-hydroxy-10, β-D-glucopyranosyloxy-11-dodecen-6,8-diynoate, methyl-β-D-glucopyranosyl helianthenate A and B.

Four tuber-forming substances were isolated from the leaves: jasmonic acid, methyl β-D-glucopyranosyl tuberonate and two new polyacetylene compounds, methyl 10-*O*-glucopyranosyl helianthenate A and methyl 8-*O*-glucopyranosyl helianthenate B (Matsuura et al. 1993b); four polyacetylenic glucosides were characterised as methyl 10-β-D-glucopyranosyloxy-3-hydroxy-11-dodecene-6,8-dynoate, the aglycone part named helianthenic acid C; methyl 9-β-D-glucopyranosyloxy-10-undecen-5,7-diynoate, the aglycone part named helianthenic acid D; (4*E*) methyl 10-β-D-glucopyranosyloxy-3-hydroxy-4,11-dodecadiene-6,8-diynoate, the aglycone part named helianthenic acid E and (8*Z*) 10-β-D-glucopyranosyloxy-8-decene-4,6-diynoate the aglycone part named helianthenic F (Matsuura et al. 1993a); six sesquiterpenoids, α-acetoxypinnatifidin; α-hydroxypinnatifidin; budlein A; 17, 18-dehydroviguiepinin; 4,15-isoatriplicolide angelate and 4,15-isoatriplicolide methacrylate (Baba et al. 2005) were isolated from the leaves. Two Jerusalem artichoke chemotypes were found: one was characterised by dominance of 1,10-epoxidised heliangolides and the other by 1-keto-2,3-unsaturated-furanoheliangolides; a total of 19 such sesquiterpene lactones were found in the leaf capitate glandular trichomes (Spring 1991); 7 chlorogenic acids comprise three caffeoylquinic acids, one feruloylquinic acid and three dicaffeoylquinic acids (Yuan et al. 2008c). Four cytotoxic sesquiterpene lactones, $\Delta^{4,15}$-isoatripliciolide tiglate, $\Delta^{4,15}$-isoatripliciolide methacrylates, budlein A isobutylate and budlein A tiglate, were isolated from the CH_2Cl_2 leaf extract (Choi et al. 2012). Eleven sesquiterpene lactones including a new sesquiterpene lactone of 3-hydroxy-8β-tigloyloxy-1, 10-dehydroariglovin and two known flavones were isolated from the leaves (Yuan et al. 2013).

Two new epoxy steroids, 5*α*,8*α*-epidioxy-22*β*,23*β*-epoxyergosta-6-en-3*β*-ol and 5*α*,8*α*-epidioxy-22*α*,23*α*-epoxyergosta-6-en-3*β*-ol, and ten known steroids including (24*R*)-5*α*,8*α*-epidioxyergosta-6-en-3*β*-ol; (22*E*,24*R*)-5*α*,8*α*-epidioxyergosta-6,22-dien-3*β*-ol; (22*E*,24*R*)-5*α*,8*α*-epidioxyergosta-6,9(11),22-trien-3*β*-ol; *β*-sitosterol; sitost-5-en-3*β*-ol acetate; 7*α*-hydroxysitosterol; schleicheol 2; (24*R*)-24-ethyl-5*α*-cholestane-3*β*,5*α*,6*β*-triol; 7*α*-hydroxystigmasterol and stigmasterol were isolated from the leaves of *Helianthus tuberosus* grown in Laizhou salinised land (Li et al. 2011).

Other Aerial Part Phytochemicals

Stems were reported to contain water-soluble polysaccharides (WSPS) 1.4 %, pectinic substances 4.0 %, soluble sugars in alcohol 20.0 % and hemicelluloses 8.0 % (Rakhimov et al. 2011). Lipid composition of Jerusalem artichoke stems was reported as lipids 1.2 %, moisture and volatiles 56.8 %, acid number 5.8 mg KOH, chlorophyll a 11.2 mg/g, chlorophyll b 4.6 mg/g, total carotenoids

1.6 mg/g, fatty acids after saponification 30.3 %, unsaponifiable substances 16.1 %, neutral lipids 58.3 %, glucolipids 35.2 % and phospholipids 6.5 % (Talipova 2001). The fatty composition of the stems was reported as total saturated fatty acids 47.4 %, 12:0 (lauric acid) 0 %, 14:0 (myristic acid) 1.5 %, 16:0 (palmitic acid) 45 %, 18:0 (stearic acid) 0.9 %, total unsaturated fatty acids 52.6 %, 18:1(oleic acid) 2.3 %, 18:2 (linoleic acid) 9.8 % and 18:3 (linolenic acid) 40.5 % (Talipova 2001).

Nine diterpenoid and sesquiterpene lactone were isolated from the chloroform-soluble fraction of the methanol extract of the whole plant: *ent*-17-oxokaur-15(16)-en-19-oic acid; *ent*-17-hydroxykaur-15(16)-en-19-oic acid; *ent*-15β-hydroxykaur-16(17)-en-19-oic acid methyl ester; *ent*-15-*nor*-14-oxolabda-8(17),12*E*-dien-18-oic acid; 4,15-isoatriplicolide angelate; 4,15-isoatriplicolide methacrylate; (+)-pinoresinol; (−)-loliolide and vanillin (Pan et al. 2008, 2009).

Allelochemical salicylic acid (*o*-hydroxybenzoic acid) and the closely related compound *p*-hydroxybenzaldehyde, as well as minor quantities of *o*-coumarinic acid and coumarin, were found in the diethyl ether shoot extract (Tesio et al. 2011).

Studies using explants of the stem of *Coleus blumei* and the storage tissue of *Helianthus tuberosus* found the pentose phosphate pathway as a source of NADPH for lignin synthesis (Pyrke and ap Rees 1977). Significant amounts of ^{3}H and ^{14}C were recovered in syringaldehyde, vanillin, *p*-hydroxybenzaldehyde and ligothio-glycollic acid from the explants of *Coleus* and *Helianthus*. The $^{3}H/^{14}C$ ratios in these derivatives and preparations of lignin indicated that much of the reducing power for lignin synthesis comes from the pentose phosphate pathway. An extract from Jerusalem artichoke shoots exhibited important adenine phosphoribosyltransferase activity (Le Floc'h and Lafleuriel 1978). The results suggested that adenine phosphoribosyltransferase *of Helianthus tuberosus* had a key role in the purine salvage pathway. The presence of adenosine and inosine–guanosine nucleosidases (Le Floc'h and Lafleuriel 1981) and hypoxanthine–guanine and adenine phosphoribosyltransferase (Le Floc'h et al. 1982) were found in the shoots. Jerusalem artichoke had been reported to contain low levels of polyamines (putrescine, spermidine or spermine) and explants from its dormant tuber afford a natural polyamine-deficient model for polyamine research in plants (Tassoni et al. 2010).

Transglutaminase activity was found in the crude extract of sprout apices of *Helianthus tuberosus* tubers (Serafini-Fracassini et al. 1988) and in activated slices of medullary parenchyma tuber tissues (Serafini-Fracassini et al. 1989). Transglutaminase was able to covalently bind polyamines (spermidine, spermine, putrescine) to endogenous substrates of different molecular weights in-vitro. The main bound polyamine was putrescine. Plant transglutaminases displayed characteristics which were different from those of animal transglutaminases. Transglutaminase activity was also demonstrated in green (leaves) and nongreen tissues (flower buds) (Falcone et al. 1993) and during greening and growth of *Helianthus tuberosus* explants developed from dormant tubers in-vitro (Del Duca et al. 1993). This enzyme activity, low in dormant tubers, increased in both explants; considerably in untreated greening explants but much less in 2,4-D-treated growing ones. They also found that light activated transglutaminase conjugation of polyamines to thylakoid proteins in *H. tuberosus* chloroplasts (Dondini et al. 2003). The protective effect on chloroplasts under photo-damage, stress or senescence conditions attributed to free polyamines was elucidated with respect to the occurrence of polyamine conjugates catalysed by transglutaminases. In a recent study, they reported that immature cells of etiolated apices of sprouts growing from *H. tuberous* tubers exhibited Ca^{2+}-dependent transglutaminase activity on fibronectin (more efficiently) and dimethylcasein as substrates (Beninati et al. 2013). Three main transglutaminase bands of about 85, 75 and 58 kDa were isolated. These three fractions had catalytic activity as catalysed polyamine conjugation to N-benzyloxycarbonyl-L-γ-glutaminyl-l-leucine (*Z*-L-Gln-L-Leu) and the corresponding glutamyl derivatives were identified. Their findings suggested that multiple transglutaminase forms were active in the same organ.

Antioxidant Activity

Tuber peel of tubers were found to contain relatively high levels of total phenolics (39–129 mg GAE/100 g FW) and exhibited high antioxidant capacity (98–296 mg ascorbic acid equivalents/100 g) (Seljåsen and Slimestad 2007). The level of total phenols was correlated to the antioxidant capacity. The flesh of tubers contained very low levels of phenols, and antioxidant capacity was not detected for any of the cultivars.

Studies showed that the flavonoids extract (FE) from Jerusalem artichoke had strong DPPH radical scavenging activities (Liu et al. 2009). DPPH radical scavenging activity of FE (95.2 %) was more potent than BHT (77.3 %) and close to the ascorbic acid (97.7 %). In addition, the antioxidation capability of FE was confirmed in lard system, and it was similar to BHT and rutin. Another study showed that the scavenging ability of flavonoid from *H. tuberosus* leaves on superoxide and hydroxyl radicals increased with the increase of flavonoid concentration, up to 66.45 and 69.33 %, respectively, when the flavonoid concentration was 100 μg/mL (Yang et al. 2011). Flavonoid from *H. tuberosus* leaves also had good antioxidant activity on lard and could inhibit the increase of polyphenol oxidase. A more recent study found Jerusalem artichoke leaves to be a potential source of natural antioxidants (Yuan et al. 2012b). The ethyl acetate leaf fraction contained the highest total phenolic content (266.69 mg GAE/g dry extract) accompanied by the strongest free radical scavenging abilities. Six phenolic compounds which strongly quenched free radicals were separated from ethyl acetate fraction. Among them, 3-*O*-caffeoylquinic acid and 1,5-dicaffeoylquinic acid played a dominant role due to their strong free radical scavenging abilities and their high contents. The content of 3-*O*-caffeoylquinic acid in *n*-butanol fraction was 74.58 mg/g, while 1,5-dicaffeoylquinic acid in ethyl acetate fraction was 104.51 mg/g.

Studies by Kim et al. (2010) found that high hydrostatic pressure treatment of fermented Jerusalem artichoke tubers with enzymes significantly improved the extractability of bioactive phenolics and fructooligosaccharides compared to conventional water extraction or high hydrostatic pressure alone. Also, 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity and superoxide dismutase (SOD)-like activity were enhanced compared to the control group.

Antidiabetic and Hypolipidaemic Activities

Due to its low polyamine contents and the abundance of inulin, which could be converted into fructose, Barta and Rosta (1958) in their studies on sugar metabolism of diabetic children suggested the preferential utilisation of Jerusalem artichoke tuber in the diet of people with special needs. In a study of 28 diabetic subjects, daily intake of fructooligosaccharides by 18 diabetic subjects for 2 weeks ameliorated the derangements of carbohydrate and lipid metabolism in diabetic subjects in comparison to ten control diabetic subjects administered with sucrose (Yamashita et al. 1984). The levels of serum HDL cholesterol, triacylglycerides or free fatty acids were not significantly affected either by fructooligosaccharides or sucrose. In an animal study, daily administration of a 10 % (w/w) oligofructose (OFS)-containing diet to normolipidaemic male rats resulted in a decrease in plasma triacylglycerides, phospholipids and cholesterol (Fiordaliso et al. 1995). The triglyceride-lowering effect was observed after 1 week and lasted for at least 16 weeks and was associated with a reduction in plasma very-low-density lipoproteins, indicating that the hypolipidaemic effect of OFS may be due to changes in liver lipid metabolism. They also found that chronic feeding of an OFS-supplemented diet to rats significantly reduced the capacity of isolated hepatocytes to synthesise triacylglycerides from palmitate. Results of a study of 35 patients aged 46–58 with type 2 diabetes mellitus by Meshcheriakova et al. (1995) did not support the use of Jerusalem artichoke as dietary treatment of non-insulin-dependent diabetes mellitus. It was shown that experimental diet containing topinambur caused slight increas-

ing of postprandial hyperglycaemia. In patients eating experimental diet with reduced caloric contents, an increase of serum blood triglyceride level was observed.

In a double-blind randomised placebo-controlled parallel study of 54 healthy middle-aged men and women with moderately raised total plasma cholesterol (TC) and triacylglycerol (TAG) levels, daily addition of 10 g inulin to the diet significantly reduced fasting insulin concentrations during the 8-week test period and resulted in lower plasma TAG levels, particularly in subjects in whom fasting TAG levels were greater than 1.5 mmol/L (Jackson et al. 1999). In a randomised, double-blind, crossover design with no washout period of 12 hypercholesterolaemic men, dietary inulin supplementation was found to improve blood lipid profiles and altered the colonic environment in a manner that may be beneficial (Causey et al. 2000). Daily intake of 20 g of inulin significantly reduced serum triacylglycerides by 40 mg/dL. A trend towards a reduction in serum cholesterol was observed, and trends towards short-chain fatty acid (SCFA) profile changes were also observed after inulin administration. Jerusalem artichoke tuber, a rich source for fructooligosaccharides (e.g. inulin), was reported to act as sweeteners that do not affect blood sugar levels after ingestion and could be tolerated by diabetics (Seljåsen and Slimestad 2007). Fructooligosaccharides made up 30–54 % of total carbohydrates, and the rest were sugars (mainly sucrose and low levels of fructose). Righetti et al. (2008) found that in comparison to soya bean products, tofu and soy sauce, the edible part (parenchymatous medulla tissue) of Jerusalem artichoke tuber contained very low levels of polyamines, which preferentially accumulated in the buds. Their data suggested a preferential utilisation of *Helianthus* tuber in the diet of people with special needs, such as patients treated by chemotherapy and patients with diabetes.

Animal studies showed Jerusalem artichoke (JA) as a source of inulin was effective in modifying intestinal characteristics, blood metabolites and liver enzymes in laying hens (Yildiz et al. 2008). Although, with unchanged serum cholesterol and albumen content, 5 % JA increased glucose and decreased fructose, triglyceride and total protein contents when compared with control diet. In contrast 10 % JA reduced serum glucose as well as fructose levels. Serum aspartate aminotransferase levels were increased by 5 % JA in addition, and alkaline phosphatase levels were decreased by l0 % JA. Administration of the ethanol extract of *H. tuberosus* tuber exhibited an inhibitory effect (24.5 %) on diabetic rat kidney tissue thiobarbituric acid reactive substance (TBARS) levels but did not restore GSH (reduced glutathione) levels in the kidney, liver and heart tissues of diabetic rats (Aslan et al. 2010). Studies by Yang et al. (2012) reported that Jerusalem artichoke and chungkookjang (fermented soybeans) enhanced glucose tolerance in different manners and exhibited partially additive and complementary effects by reversing insulin resistance and enhancing β-cell function in diabetic rats. The combined treatment reduced visceral fat without modulating energy intake compared to the diabetic control.

Animal studies showed that Jerusalem artichoke tuber syrup possessed hypoglycaemic activity (Rakhimov et al. 2011). The hypoglycaemic effect after just a single administration to rats at a dose of 0.4 mL/100 g was 21.2 % after 3 hours; the syrup was more active than arfazetin (11 %) and adebit (14.2 %). Blood sugar level continued to remain at a reduced level over the 2-week period of multiple administrations of the syrup, dropping by 23.3 and 27.8 % with respect to the initial value after 7 and 14 days. During the same periods, blood glucose dropped by 14.1 and 16.5 %, respectively, for arfazetin and by 18.8 and 19.9 % for adebit. The hypoglycaemic effect of the syrup was even more evident during disrupted carbohydrate exchange when the initial blood glucose level was rather high. A pronounced hypoglycaemic effect of Jerusalem artichoke syrup was also determined for alloxan hyperglycaemia and alloxan diabetes. Administration of the syrup for a week lowered the blood glucose level by 31.7 %, while arfazetin exhibited a hypoglycaemic effect of 10.4 % and adebit by 25.4 %. The

hypoglycaemic properties of Jerusalem artichoke syrup in tests on normal animals were also manifested to a greater extent than adebit. Their effects were equivalent overall in tests on animals with hyperglycaemia.

Oral administration of Jerusalem artichoke inulin was found to reduce blood glucose and lipid in streptozotocin-induced diabetic rats (Park 2011). Blood glucose was significantly lowered in the inulin-administrated groups. Compared with diabetic control rats, the decrease of blood glucose in the inulin-administrated groups was 60.73–63.4 % in the fourth week and showed a tendency of gradual recovery. Triacylglycerides in the blood, total cholesterol, LDLC and atherogenic index were significantly decreased by 27.13–32.91, 22.42–23.31, 35.41–38.28 and 49.71–57.11 %, respectively, in the inulin-administrated groups compared to the diabetic control group. Conversely, HDLC was significantly increased by 24.89–47.20 %. The weights of the liver, kidney and heart but not the spleen were significantly heavy in the diabetic control group, compared with the inulin-administrated groups.

A study of eight healthy subjects found that after *H. tuberosus* fructans ingestion blood glucose (BG), insulin increments were very low, much lower than after fructose ingestion, whereas hydrogen production was much higher and fructans were malabsorbed (Rumessen et al. 1990). Areas under BG curves tended to be smaller when 10 g fructans was added to a 50 g wheat starch meal, but there was no apparent interference with starch absorption. Orocaecal transit times were longer for fructans than for lactulose and fructose. In a 4-week double-blind crossover design study of 12 healthy subjects, 20 g of a mixture of short-chain fructooligosaccharides (SC-FOS), namely, kestose (glucose–fructose–fructose, GF2), nystose (GF3) and fructosyl–nystose (GF4) decreased basal hepatic glucose production but had no detectable effect on insulin-stimulated glucose metabolism in healthy subjects (Luo et al. 1996). Serum triacylglycerines, total and high-density lipoprotein cholesterol, apolipoproteins A-I and B and lipoprotein (a) were not modified by FOS. They found that colonic fermentation pattern of indigestible carbohydrates may be relevant to predicting their metabolic effects. In another double-blind crossover design study of six men and four women with type 2 diabetes, 4 weeks of 20 g/day of short-chain fructooligosaccharides (SC-FOS) had no effect on glucose and lipid metabolism. SC-FOS did not modify fasting plasma glucose and insulin concentrations or basal hepatic glucose production.

In a randomised, single-blind, crossover design clinical study involving 20 patients with type 2 diabetes, Alles et al (1999) found that 20 days of dietary supplementation with fructooligosaccharides had no major effect on blood glucose, serum lipids or serum acetate in patients. This lack of effect was not due to changes in dietary intake, insufficient statistical power or noncompliance of the patients. Their results did not support earlier claims that fructooligosaccharides lowered fasting glycaemia and serum total cholesterol concentrations, possibly via effects of short-chain fatty acids produced during fermentation.

Of nine studies conducted in both normo- and moderately hyperlipidaemic subjects that investigated the response of blood lipids (usually total and LDL cholesterol and triacylglycerol) to inulin or oligofructose supplementation in human volunteers, three had observed no effects of inulin or oligofructose on blood levels of cholesterol or triacylglycerol and three had shown significant reductions in triacylglycerol, while four have shown modest reductions in total and LDL cholesterol (Williams and Jackson 2002). They stated that variability in response may be a reflection of differences in background diet or the experimental foods used, and it did not appear to be due to differences in the type or dose of oligosaccharides used nor the duration of the studies.

Anticancer Activity

Pierre et al. (1997) showed that short-chain fructooligosaccharides counteracted advanced stages of colon carcinogenesis in mice, possibly via stimulation of antitumoral immunity by

modulation of the colonic ecosystem. Wounds from Jerusalem artichoke tubers were reported to excrete bioactive metabolites including proteins that were cytotoxic to some human tumour cell lines, especially the human mammary tumour cells MDA-MB-231 (Griffaut et al. 2007). The active agent was found to contain an 18 kDa superoxide dismutase (SOD) polypeptide, tightly linked to a 28 kDa alkaline phosphatase (AP) polypeptide. The superoxide dismutase polypeptide was shown to be involved in the antitumour activity, but the presence of smaller factors (MW <10 kDa), such as salicylic acid, could enhance this activity. Extracts of *H. tuberosus* aerial parts were found to possess antimicrobial and antifungal activities, and heliangin, a germacrene sesquiterpene lactone isolated from the leaves of this plant, exhibited significant activity in-vitro against Ehrlich ascites carcinoma cells (Ahmed et al. 2005).

Two germacrene-type sesquiterpene lactones isolated from Jerusalem artichoke, 4,15-isoatriplicolide angelate and 4,15-isoatriplicolide methacrylate, were found to be cytotoxic on MCF-7 human breast cancer cell line (Pan et al. 2009). The CH_2Cl_2 extract of *Helianthus tuberosus* leaves exhibited potent cytotoxic activity against the cultured human tumour cell lines including lung carcinoma A-549, adenocarcinoma SK-OV-3, malignant melanoma SK-MEL-2, central nervous system tumour XF498 and colon adenocarcinoma HCT-15 in-vitro (Choi et al. 2012). Of the four cytotoxic sesquiterpene lactones isolated from the extract, $\Delta^{4,15}$-isoatripliciolide tiglate showed the most potent cytotoxic activity ($0.26\ \mu M < ED_{50} < 2.16\ \mu M$) against all of the cell lines tested. Eleven sesquiterpene lactones isolated from leaves exhibited cytotoxicity against MCF-7, A549 and HeLa cancer cells lines, while two isolated flavones showed selective inhibitory activity against HeLa cell lines (Yuan et al. 2013). Among them compound 3 exhibited significant growth inhibitory activity against all three cell lines and the IC_{50} values of compound 3 against MCF-7, A549 and HeLa were 1.97, 7.79 and 9.87 μg/ml, respectively.

Antimicrobial Activity

The new epoxy steroids compounds from the leaves, 5α,8α-epidioxy-22*β*,23*β*-epoxyergosta-6-en-3*β*-ol (**1**) and 5α,8α-epidioxy-22α,23α-epoxyergosta-6-en-3*β*-ol (**2**), exhibited weak antibacterial activity and no antifungal activity (Li et al. 2011). Compound (1) showed weak inhibitory activity against *Escherichia coli* and *Staphylococcus aureus* and compound (2) against *Escherichia coli*.

Heltuba, lectin from *H. tuberosus* tubers, was highly specific for the disaccharides Man alpha 1-3 Man or Man alpha 1-2 Man, two carbohydrates that were particularly abundant in the glycoconjugates exposed on the surface of viruses, bacteria and fungi and on the epithelial cells along the gastrointestinal tract of lower animals, indicating heltuba to be a good candidate as a defence protein against plant pathogens or predators (Bourne et al. 1999).

Prebiotic/Probiotic/Synbiotic Activities

Studies with rats and in-vitro studies with bacteria isolated from the large intestine of man showed that inulin (a prebiotic) was almost completely metabolised in the large intestine where it provided a selective growth substrate for bifidobacteria (Hidaka et al. 1986; Wang and Gibson 1993). Animal studies by Campbell et al. (1997) found that dietary incorporation of fermentable, indigestible oligosaccharides, by providing short-chain fatty acids, lowering pH and increasing caecal bifidobacteria, may be beneficial in improving gastrointestinal health.

In a study of 12 healthy adult human subjects, 4 g fructooligosaccharide (neosugar)/day for 42 days altered the faecal flora (increased bifidobacteria densities) in a manner perceived as beneficial by decreasing activities of some reductive enzymes, β-glucuronidase and glycocholic acid hydroxylase (Buddington et al. 1996). In another study of 20 volunteers, ingestion of fructooligosaccharides (FOS), at a

clinically tolerated dose of 12.5 g/day for three consecutive 12-day periods, led to an increase in colonic bifidobacteria and β-fructosidase activity (Bouhnik et al. 1996). FOS ingestion had no significant effect on the faecal total anaerobes, pH, the activities of nitroreductase, azoreductase and β-glucuronidase and the concentrations of bile acids and neutral sterols. The observed effect was not associated in healthy humans with beneficial changes in various factors potentially involved in the pathogenesis of colonic cancer. In a study of eight healthy human subjects, prolonged administration (up to 21 days) of transgalacto-oligosaccharides, at a dose which did not induce digestive symptoms, increased the number of bifidobacteria, altered the fermentative activity of colonic flora and caused a significant decrease in breath hydrogen in humans. Short-chain fructooligosaccharide (SC-FOS) administration dose dependently increased faecal bifidobacteria in healthy humans (Bouhnik et al. 1999). A significant correlation between the dose of SC-FOS ingested and the faecal bifidobacteria counts was observed at day 8. In subsequent studies they showed that 4-week 8 g/day SC-FOS ingestion was well tolerated and led to a significant increase in faecal bifidobacteria and cholesterol excretion in healthy elderly subjects (Bouhnik et al. 2007).

Studies by Kocsis et al. (2007) on the effect of seasonal changes and varieties on the soluble carbohydrate (sucrose, inulin) profiles would help in selecting suitable cultivars and deciding the appropriate harvest time for an optimum processing of tubers for their application as prebiotic and novel food component. They found a high content (60–65 % of dry mass DM) of water-soluble carbohydrates (sucrose, inulin) in early harvested varieties (Bella and Bianka) and middle early varieties (Topstar and Gigant) harvested 22–25 weeks after planting. In late varieties (Waldspindel, Violet de Rennes, Rote Zonenkugel), a similar amount was obtained (55–60 % of DM) when harvested 29–33 weeks after planting. There was a distinctive impact on maturing process as well as frost period alterations which resulted in conversion of high polymer inulin to low polymer inulin as well as to sucrose. Studies showed that *Lactobacillus* strains could be used for the fermentation of Jerusalem artichoke tuber juice (rich in the prebiotic inulin), which in fermented form could be used alone or mixed with other raw food material, as a new synbiotic functional food (Zalán et al. 2011).

Adding dried Jerusalem artichoke to diets of entire male pigs 1 week before slaughter resulted in a dose-dependent decrease in skatole levels in the hindgut and adipose tissue (Vhile et al. 2012). The reduced skatole levels might be related to the decrease in *Clostridium perfringens* in the colon and rectum and enterobacteria in the colon and also to the increase in short-chain fatty acids (SCFA) with subsequent reduction in pH.

In a 4 week, double-blind, randomised, placebo-controlled trial involving 66 adult men with functional constipation, dietary supplementation (twice daily) of a symbiotic mixture comprising fructooligosaccharides (prebiotics) and *Bifidobacterium*, *Lactobacillus* and *Streptococcus* species (probiotics) significantly increased stool frequency compared to control at week 2 (Fateh et al. 2011). In another randomised, double-blind, placebo-controlled study of 20 women and 16 men (25–45 years old), dietary administration of a commercialised synbiotic product containing *Lactobacillus acidophilus* La5, *Bifidobacterium animalis* ssp. *lactis* Bb-12, *Lactobacillus delbrueckii* ssp. *bulgaricus*, *Lactobacillus paracasei* ssp. *paracasei*, *Streptococcus thermophilus* and fructooligosaccharides caused a significant improvement in overall self-reported gastrointestinal symptoms and bowel habit (Nova et al. 2011). A marginal effect of treatment was observed with L-selectin, which showed a significant decrease in the synbiotic group. In a randomised, double-blind, placebo-controlled study involving 100 constipated adult women, dietary supplementation with a synbiotic composed of fructooligosaccharides (prebiotics) with *Lactobacillus* and *Bifidobacterium* (probiotics) improved evacuation parameters and constipation intensity of chronically constipated women, without influencing abdominal symptom (Waitzberg et al. 2012).

Immunomodulatory Activity

Gamma inulin (g-IN), a polymorph identified as the active component of inulin preparations that specifically activates the alternative pathway of complement (APC) that is central to many leucocyte functions, including B cell activation, was found to be a potent adjuvant for both humoral- and cell-mediated responses to a variety of antigens (Cooper and Steele 1988). Gamma inulin and especially Algammulin (alum and inulin) were reported to be potent enhancers of the Th1 immune response pathway, boosting seroconversion rates and immunological memory in protective Ab classes and enhancing cell-mediated immunity (Cooper 1995). They are also Th2 pathway enhancers, especially for IgA, and the emphasis on Th2 might be varied by altering the alum-to-inulin ratio in the final formulation. Their primary targets in-vivo were probably lymphocytes rather than macrophages. Gamma inulin-based adjuvants comprise new, safe, potent and attractive candidates for enhancing responses to human and veterinary vaccines, especially those requiring cell-mediated defences. Finely divided, insoluble inulin (gamma inulin), given intraperitoneally (i.p.) to C57BL mice 1–3 days after i.p. B16 melanoma cells, very significantly increased their mean survival time (MST) in low doses (Cooper and Carter 1986). The gamma inulin was pure and free of endotoxin and soluble inulin and was developed as a potent reagent specific for activating the alternative pathway of complement (APC). The minimum i.p. dose of gamma inulin found to activate serum APC in-vivo was 50 mcg (2.5 mg/kg), i.e. close to the minimum antitumour dose.

Results of studies suggested that dietary fructooligosaccharides (FOC) supplementation to BALB/c mice altered the intestinal environment of microflora and led to upregulation of immunoglobulin A (IgA) secretion in CD4+ Peyer's patch cells in intestinal mucosa and to suppression of the systemic immune response to type 2 helper T (Th2) dominant (Hosono et al. 2003). Similarly, it was shown that dietary FOS increased the intestinal IgA response and immunoglobulin receptor (pIgR) expression in the small intestine as well as the colon in infant mice (Nakamura et al. 2004).

Calcium and Magnesium Absorption Activity

Studies found that feeding rats with fructooligosaccharides significantly increased calcium and magnesium absorption and that indigestible and fermentable carbohydrate facilitated colorectal absorption of calcium and magnesium (Ohta et al. 1995). Animal studies showed that the ingestion of all the tested fructans 10 % oligofructose (OF) (DP (av) 4) or 10 % HP-inulin (DP (av) 25), a blend of 50 % OF and 50 % HP-inulin 10 % oligofructose (OF) (DP (av) 4) or 10 % HP-inulin (DP (av) 25) and a blend of 50 % OF and 50 % HP-inulin led to a considerable caecal fermentation in rats (Coudray et al. 2003). All tested compounds increased the intestinal absorption and balance of Mg significantly. Also, all tested compounds increased the intestinal absorption and balance of Ca numerically, but only the blend OF + HP-inulin increased apparent intestinal absorption and balance of Ca significantly.

Traditional Medicinal Uses

Jerusalem artichoke is reported to be aperient, aphrodisiac, cholagogue, diuretic, spermatogenic, stomachic and tonic. It has been reported to be used as a folk remedy for diabetes and rheumatism (Duke and Wain 1981). Additionally, the leaves of *H. tuberosus* showed antipyretic, analgesic, anti-inflammatory effects and were therefore used as folk medicine in China for the treatment of bone fracture, skin wound, swelling and pain (Yuan et al. 2008c, 2012b). *Helianthus tuberosus* tubers are used as folk remedy for the treatment of diabetes in Turkey (Aslan et al. 2010). *H. tuberosus* has aperient, aphrodisiac, cholagogue, diuretic, spermatogenic, stomachic and tonic effects and has been utilised as a folk medicine for the treatment of rheumatism for the presence of inulin, which can be converted into fructose (Kays and Nottingham 2007).

Other Uses

Inulin Production

Helianthus tuberosus had proven to be a rich source of inulin and was well characterised as potential crops for commercial fructose production (Fleming and GrootWassink 1979).

The Jerusalem artichoke is an excellent crop for inulin production, and the United States, Russia and some European countries use it in their food and in pharmaceutical industries as a raw material because of its valuable properties (Ziyan and Pekyardimci 2003).

Taha et al. (2012) combined the use of biotic elicitor, *Aspergillus niger*, and methyl jasmonate to enhance inulin accumulation in Jerusalem artichoke cell cultures.

Fructans can be used in the food industry and in several nonfood industrial and medical applications, and Jerusalem artichoke accumulates fructans as storage reserves and is widely appreciated for its high fructans yield with low input techniques (Monti et al. 2005).

Animal Feed

Jerusalem artichoke herbage was found to be a good source of a high-quality protein isolate rich in lysine and may provide good ruminant feed (Rawate and Hill 1985).

Studies suggested that whether Jerusalem artichoke is mixed with other forbs or grasses in a pasture or hay or whether it is used as silage, it appeared to have the potential to provide a satisfactory nutrition level for ruminants (Seiler 1988). Crude protein (CP) concentrations of 140 g/kg and above occurred in leaves of 11 of 19 genotypes at the vegetative stage, and 15 of the 19 genotypes had whole plant CP of 60–90 g/kg at all stages of maturity. Nutritionally adequate amounts of Ca (2–8.6 g/kg), Mg (1 g/kg) and K (6.5 g/kg) were present in leaves, stems and whole plants of all genotypes at all stages of maturity. Leaves, stems and whole plants of most genotypes had suboptimal P (<2 g/kg) levels for ruminants at all stages of maturity. Nutritionally adequate amounts of CP, Ca, Mg and P were present in whole seeds of most genotypes. Seiler (1993) found the cultivated Jerusalem artichoke 'Sunchoke' had the highest forage yield (6.3 Mg/ha) which was comparable to some common forage species. The cultivated genotypes also had the highest mean tuber yield (7.19 Mg/ha). At maturity, the allocation of biomass for Jerusalem artichoke was 68, 23 and 9 % for stems, leaves and heads, respectively. At flowering, the whole plant concentration of in-vitro digestible dry matter (IVDDM) was above the accepted level (598 g/kg) for adequate animal nutrition for most. *H. tuberosus* is an economically important crop species, with aerial parts, and the tubers are used as forage for cattle (Long et al. 2008). Tubers contain adequate amounts of macro- and microelements for use as cattle feed. There was an adequate amount of studied mineral elements except for phosphorus in Jerusalem artichoke herbage for use as ruminant cattle feed (Terzić et al. 2012). Of all the analysed essential elements in leaves (N, P, Ca, Mg, K, Fe, Mn, Zn and Cu), Ca was the most abundant (36 g/kg), while in tubers it was only the fourth of the nine analysed elements. The Ca/P ratio was approximately the same in tubers of all accessions which corresponds to a desired ratio for cattle feed (1:1–2:1). The leaves contained 18 times more Ca than P. Studies by Meijer and Mathijssen (1991) have suggested that *H. tuberosus* can be utilised as a stalk crop, which can be harvested at the beginning of flowering, since its above-ground biomass is high and stores temporary amounts of fructans in the stalk. Then the tops can be fed fresh or ensiled, although the forage does not ensile well because of its high concentration of soluble sugars and high moisture content.

Fructose Production

Jerusalem artichoke tubers are an important source of fructose as a sweetener for the food industry (Pilnik and Vervelde 1976). Analysis involving 37 cultivars originating from France or overseas showed that among the early cultivars

studied, 'Grando' appears to be the richest with 193 mg/g fresh wt of dry matter (DM) and 508 mg/g DM of fructose (as fructan) (Chekroun et al. 1996). For fructose production, among the late white cultivars analysed, 'Kharkov' gave the best performance with 179 mg/g fresh wt of DM, 531 mg/g DM of fructose and 710 mg/g DM of total carbohydrates. The French cultivars 'Miello', 'Dub' and 'Rico' were considered in their group as the most productive with 549, 545 and 540 mg/g DM of fructose, respectively. Jerusalem artichoke can also be used as a perennial sugar (fructose) crop by only harvesting the stalks for many years around the flowering time before the carbohydrate translocation to the tubers occurs (D'egidio et al. 1998). The possibility of exploiting the stalk of the plant, instead of the tuber, as a source of sugar was reported by Caserta and Cervigni (1991) using a late hybrid characterised by well-developed stalks and low production of tubers on marginal land. Glucose-free fructose production from Jerusalem artichoke inulin was achieved using recombinant inulinase-secreting strain of *Saccharomyces cerevisiae* in a one-step fermentation (Yu et al. 2011).

Biogas, Biofuel: Ethanol, Biodiesel Production

Anaerobic digestion experiments showed that fresh and ensiled above-ground parts of the plant could produce 480–680 l biogas per kg organic material (Gunnarson et al. 1985). Their results confirmed that economic biogas production from above-ground parts of Jerusalem artichoke was possible under certain conditions. Jerusalem artichoke also has a great deal of unused potential as a producer of ethanol for fuel, using inulin-adapted strains of yeast for fermentation. Jerusalem artichoke tubers have been reported to have one of the highest carbohydrate yields of known agricultural crops ranging between 2,400 and 900 kg sugars per acre/year which is equivalent to about 1,000–2,400 kg ethanol/acre/year assuming an ethanol yield of 80 % of the theoretical (Margaritis et al. 1981). Margaritis et al. (1981) used batch of Jerusalem artichoke tubers by seven yeasts and *Zymomonas mobilis* to convert to ethanol and microbial biomass. Williams and Ziobro (1982) used *Kluyveromyces fragilis* fermentation for the production of ethanol from Jerusalem artichoke tubers and inulin. Groot Wassink and Fleming (1980) found that *Kluyveromyces fragilis* inulase (β-fructofuranosidase) to be a better alternative to *Saccharomyces cerevisiae* invertase presently used in industry for fermentation. *H. tuberosus* was used as a raw material for the production of motor fuel alcohol during the Second World War and had been sporadically used for this purpose until now (Chekroun et al. 1996).

Studies by Cheng et al. (2009) showed that it was feasible to produce biodiesel from Jerusalem artichoke tuber using heterotrophic microalga *Chlorella protothecoides*. Lipids produced could be converted into biodiesel by transesterification. Cetane acid methyl ester, linoleic acid methyl ester and oleic acid methyl ester were the dominating components of the biodiesel produced. Unsaturated fatty acids methyl ester constituted over 82 % of the total biodiesel content.

The yield of ethanol from Jerusalem artichoke tubers by using *Kluyveromyces marxianus* in batch fermentation was calculated to be in the range of 1,400 kg ethanol/acre/year to a maximum of 2,700 kg ethanol/acre/year (Margaritis and Bajpai 1982). Single-cell protein yields for *K. marxianus* were calculated to range between 130 and 250 kg dry wt cell/acre/year. Yeasts with inulinase activity could be used to produce ethanol from Jerusalem artichoke tubers with good profitability, obtaining 25–65 hl ethanol/ha with by-products usable as feed (Guiraud et al. 1981). Guiraud et al. (1982) obtained the following fermentation yield from fermentation of Jerusalem artichoke extract by various yeast cultivated in anaerobiosis: *Candida kefyr* (95 %), *C. macedoniensis* (91.5 %), *C. pseudotropicalis* (86.5 %), *Kluyveromyces marxianus* (98 %), *K. fragilis* (95 %), *Saccharomyces fermentati* (94 %), *Schwanniomyces castellii* (89 %) and *Torulopsis colliculosa* (96.5 %). Guiraud et al. (1986) found that using an aerobic phase to increase biomass of early harvest tubers prior to the anaerobic fermentation by *Kluyveromyces marxianus* could

enhance ethanol yield. The ethanol yield after enzymatic hydrolysis before fermentation (expressed as % theoretical yield) was 78.3–90.0 % and 72.4–84.2 % for the bacterium *Zymomonas mobilis* and yeasts (distillery yeast *Saccharomyces cerevisiae* and a yeast with inulinase activity), respectively, in tubers as well as 78.3–88.1 % and 74.4–82.2 % for the bacterium and yeasts in juices (Szambelan et al. 2004). The yield was 2.0–9.2 % higher than after acid hydrolysis. The yeast with an active inulinase yielded better when juices were used for fermentation than on mashed tubers. Although enzymatic hydrolysis with an inulinase gave less reducing sugars, it was significantly more efficient in fermentation process. Studies by Curt et al. (2006) showed that bioethanol can be produced from Jerusalem artichoke stems, and they estimated that the potential of the stems of the mid-season/late clones for bioethanol was 38 % that of the tubers. Studies showed that the carbohydrates derived from Jerusalem artichoke stalks could be converted efficiently to ethanol by acidic hydrolysis followed by fermentation with *Saccharomyces cerevisiae* or by direct fermentation of inulin using *Kluyveromyces marxianus* strains (Negro et al. 2006). Fresh Jerusalem artichoke tubers grown in salina and irrigated with 25 and 50 % seawater were found to be sustainable feedstock for ethanol fuel production by *Kluyveromyces marxianus* fermentation; also it did not compete with other crops for arable land (Yuan et al. 2008b). The yeast *Kluyveromyces cicerisporus* was found to be a promising candidate for industrial ethanol production from Jerusalem artichoke tubers by simultaneous saccharification and fermentation approach (Yu et al. 2010).

Yuan et al. (2012a) developed a consolidated bioprocessing (CBP) strategy that integrated inulinase production, saccharification of inulin contained in Jerusalem artichoke tubers and ethanol production from sugars released from inulin by the enzyme was developed with the inulinase-producing yeast *Kluyveromyces marxianus* Y179 and fed-batch operation. Thermotolerant *Kluyveromyces marxianus* and *Saccharomyces cerevisiae* strains were found to have promising potential for bioethanol production from Jerusalem artichoke by consolidated bioprocessing (Hu et al. 2012). Kim and Kim (2014) reported a cost-effective consolidated bioprocessing strategy for bioethanol production from the whole Jerusalem artichoke plant using *Kluyveromyces marxianus*. The ethanol yield was 0.252 g ethanol per g dry biomass or 0.32 g ethanol per g fermentable sugars, with a fermentable sugar conversion rate of 60 %.

Sun et al. (2009) showed Jerusalem artichoke tuber to be a favourable substrate for 2,3-butanediol production, one of many promising bulk chemicals with wide applications for biofuel production. The application of fed-batch simultaneous saccharification and fermentation by *Klebsiella pneumoniae* for its conversion could result in a more cost-effective process. *Helianthus tuberosus* was reported to be a good source of dimethylfuran production and to be better than ethanol for biofuel production (Cao et al. 2008). 5-Hydroxymethylfurfural (HMF) was produced from monosaccharide (fructose and glucose), polysaccharide (inulin) and the Jerusalem artichoke juice by a simple one-pot reaction including hydrolysis and dehydration using solid acid under mild condition (Yang et al. 2010). A simple method for hydroxymethylfurfural (HMF) production from non-crop biomass of the Jerusalem artichoke was developed using the Fenton reaction, in a mixture of 2-butanol and water by Seo and Han (2012).

Industrial Chemical/Pharmaceutical Production

Kays and Nottingham (2007) have listed a long list of chemicals derived from Jerusalem artichoke inulin and their potential industrial uses: inulin, oligofructose, fructooligosaccharides as prebiotic ingredient in numerous foods; inulin dietary fibre as low-calorie fibre/bulking agent and thickener; inulin ingredient as fat replacement in low-calorie foods; inulin ingredient as sweetener/low-calorie sugar replacement; fructose (crystallised), fructose (syrups, high syrups) in numerous food industry uses; fructose

dianhydrides as low-calorie sweeteners; highly purified inulin for medicinal/diagnostic uses; inulin esters as plasticisers, surfactants and binders; cyclic inulooligosaccharides for many potential industrial uses; furfural solvent, used in oil refining and in resins; hydroxymethylfurfural, mannitol acetone, butanol and succinic acid for numerous industrial uses; glycerol and lactic acid for numerous food and nonfood industry uses; 1,2-propanediol for food, nonfood and medicinal uses; ethylene glycol as antifreeze; 2,3-butenediol fuel additive and use in plastics; *O*-succinylated inulin as drug carrier; methylated inulin and dialdehyde inulin as precursors for additional products; inulin carbonates for insolubilisation of biologically active molecules; *O*-(carboxymethyl) inulin as detergent binders; inulin ethers immunological assays; inulin carbamates emulsions and suspensions; inulin-amino acids for medicinal usage, *O*-(cyanoethyl) inulin paper industry usage; *O*-(3-amino-3-oxopropyl) inulin emulsifier and surfactant; *O*-(3-hydroxyimino-3-aminopropyl) inulin chemical industry uses; *O*-(aminopropyl) inulin used in detergents; *O*-(aminopropyl) inulin derivatives range of industrial uses, including cosmetics; stearoyl amide surfactant and emulsifier used in detergents; N-carboxymethylaminopropylated inulin sequestering agent for detergents; cycloinulohexaose derivatives used in cosmetics; alkoxylated inulin stabilising properties inulin phosphates thermally reversible gels; and complexing agents precipitation of heavy metals.

Compounds produced by *Lactobacillus* strains during fermentation of Jerusalem artichoke tuber juice included organic acids (lactic acid, 110–337 mmol/L; acetic acid, 0–180 mmol/L; and succinic acid, 0–79 mmol/L), hydrogen peroxide (0.25–1.77 mg/L), mannitol (0.06–3.24 g/L), acetoin and diacetyl production (Zalán et al. 2011).

Lactic acid and high yield of fructose was produced by hydrolysis of Jerusalem artichoke tubers using the commercial glucoamylases, GA-L New from Genencor (Dao et al. 2013). GA-L New was used as the inulinase and *Pediococcus acidilactici* DQ2 as the fermenting strain in the simultaneous saccharification and lactic acid fermentation of the tubers. A high lactic acid titre, yield and productivity of 111.5 g/L, 0.46 g/g DM and 1.55 g/L/hour, respectively, were obtained within 72 hours.

Ornamental and Bee Plant

Free-blooming Jerusalem artichoke cultivars are also grown as ornamental and as a source of nectar for bees.

Soil Phytoremediation and Improvement

In pot experiment studies, Jerusalem artichoke was found to remove heavy metals Cd, Pd, Ni, Cu and Zn from heavy metal-contaminated soils and accumulating them in the plant (Jasiewicz and Antonkiewicz 2002). Ma et al. (2011) reported that Jerusalem artichoke, a salt-resistant plant, has been widely cultivated in Shanxi, Heilongjiang, Shandong and Jiangsu provinces for improving salt-alkaline soils, oil-polluted soils and coal-mining soils. Several Jerusalem artichoke genotypes were found to have promising soil phytoremediation activity in removal of heavy metal pollutants like cadmium from contaminated soil (Long et al. 2013).

Antifungal Control Agents

The ethyl acetate leaf extract exerted the highest antifungal activity, with inhibitory rates of 77.91 %, 100 and 100 % against plant pathogens *Rhizoctonia solani*, *Alternaria solani* and *Botrytis cinerea*, respectively, at a concentration of 20 mg/mL (Liu et al. 2007). The crude leaf extract and its n-butanol fraction exhibited antifungal activity in-vitro against *Botrytis cinerea*, *Colletotrichum gloeosporioides*, *Phytophthora capsici* and *Rhizoctonia cerealis*, with the values of IC_{50} ranging from 2.166 to 2.534 g/L for the crude leaf extract and 0.232–1.911 g/L for *n*-butanol fraction (Chen et al. 2013). The severity of grey mould caused by *B. cinerea* was significantly

reduced by *n*-butanol fraction applied at 1 and 2 g/L with the control efficiency of 71.3 and 77.8 %, respectively, compared with commercial fungicide carbendazim. Among the phenolic acids isolated from the n-butanol fraction, caffeic acid, 3,4-dicaffeoylquinic acid and 1,5-dicaffeoylquinic acid played a dominant role and were active in bioassays against *Gibberella zeae*, with respective minimum inhibitory concentrations (MIC) being 108, 60 and 4.2 μg/mL.

Weed Management

Studies showed that diethyl ether shoot extract of *H. tuberosus* cultivar Fuseau was consistently most inhibitory to germination and seedling growth of lettuce (Tesio et al. 2010). Salicylic acid (*o*-hydroxybenzoic acid) and the closely related compound *p*-hydroxybenzaldehyde, as well as minor quantities of *o*-coumarinic acid and coumarin, were identified in the active fraction inhibiting lettuce seedling growth. Field observations provided further evidence for the allelopathic potential of *H. tuberosus* residues, as significant weed growth inhibition was observed in Jerusalem artichoke-infested plots with soil-incorporated residues in comparison to noninfested field sites, both in terms of weed seedling emergence and growth. The allelopathic potential of *H. tuberosus* may be of interest in the implementation of integrated weed management programmes in the field.

Comments

Jerusalem artichoke is propagated by tubers, and planting is usually done in the spring.

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Smallanthus sonchifolius

Scientific Name

Smallanthus sonchifolius (**Poepping and Endlicher**) **H. Robinson**

Synonyms

Polymnia sonchifolia Poepping and Endlicher, *Polymnia edulis* Wedd.

Family

Asteraceae

Common/English Names

Bolivian sunroot, Earth Apple, Strawberry jicama, Sweet root, Yacón, Yacon Strawberry

Vernacular Names

Argentina: Llacon, Llacjon, Illag'on, Yacón
Bolivia: Aricona, Aricoma, Aricuma (Aymara), Llacon, Llacjon, Llacoma, Llacón (Quechua), Illag'on, Polaco, Puhe, Racón, Shicama, Taraca, Yacón
Columbia: Arbolocao, Chicama, Colla, Jacón, Jícama, Jíquima, Jiquimilla
Ecuador: Chicama, Jicama, Jiquima, Jiquimilla, Shicama
French: Poire De Terre
Japanese: Yaakon
Peru: Aricoma (Aymara), Llacon, Llacjon, Llacoma, Llacón, (Quechua), Illag'on Polaco, Puhe, Racón, Shicama, Taraca, Yacón
Quechua: Llamón, Llaqon, Yacumpi
Spanish: Jíquima, Jiquimilla, Llacon, Yacón
Venezuela: Chicama, Colla, Jacón, Jícama, Jíquima, Jiquimilla

Origin/Distribution

Yacon is indigenous to the humid slopes of northern and central Andes from southern Columbia to northern Argentina. The area with the largest clone diversity extends from northern Bolivia to central Peru where native Quechua and Aymara names are used. Diversity of clones is more reduced in Ecuador. The plant has naturalised elsewhere in South America. It has become an important crop in Brazil especially in the state of Sao Paulo. It grows well in southern Australia, Tasmania and New Zealand, where the climate is mild and the growing season long. It has recently been introduced to the Philippines, Malaysia (Cameron Highlands), southern USA, Czech Republic, Russia, Taiwan, Korea and Japan and is now widely available in local markets.

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Agroecology

The native habitat of yacon is in areas with tropical montane climates between 1,800 and 2,800 m altitude. Although the mountain forests of central Peru and northern Bolivia are evergreen and supplied with abundant rainfall and mist during most of the year, they are subjected to a relatively dry winter period lasting 2–4 months. This drier and slightly cooler interval may generate conditions under which large tuberous roots could have an adaptive advantage. Yacon will grow in a range of climates (temperate and subtropical) and soils from sea level up to 3,200 m elevation. Optimal growth has been reported in temperatures ranging from 18 to 25 °C; aerial organs cannot withstand frost and sustain damage in temperatures below −1 °C. Mean annual rainfall of 800 mm or more is deemed optimum. Yacon thives best in light, deep, well-drained soils rich in organic matter and with neutral to slightly acidic pH.

Edible Plant Parts and Uses

Yacon tubers are crisp and sweet tasting and can be eaten raw after peeling the skin; it has a texture and flavour described as a blend of apple and watermelon. In yacon producing countries, products made from yacon root includes flour, dehydrated products, slice or chips, juices, purees and sweeteners in the form of syrup or tea with high fructooligosaccharide (FOS), and yacon leaves are dried and used for tea (NRC 1989). Both yacon root syrup and teas are popular among diabetic people and dieters because the fructose sugar (FOS) these products contain is not hydrolysed or absorbed by humans. The FOCs act as prebiotic as they encourage the proliferation of friendly probiotic bacteria in the colon that boost the immune system and help digestion. FOCs are increasing added to pastries, confectionery and dairy products (Campbell et al. 1997). Yacon and maca are already on the European market as prospective functional foods and dietary supplements, mainly for use in certain risk groups of the population, e.g. seniors, diabetics, postmenopausal women, etc. (Valentová and Ulrichová 2003). Yacon roots are a rich source of fructooligosaccharides (FOSs) and have a long use tradition as food in the Andean region (Genta et al. 2005). Yacon root is generally peeled and sliced and consumed fresh like a fruit or used in fruit salad with other fruits (Choque Delgado et al. 2013). Yacon root can also be baked or blended and its juice consumed as a refreshing beverage. Yacon and maca are already on the European market as prospective functional foods and nutraceuticals for use in certain risk groups of population (Valentová et al. 2001). Moscatto et al. (2006) found that a chocolate cake formulation with 20 % of the wheat flour replaced with yacon root meal, 153 mL of water and no inulin showed the best values for hardness (3.638 N), cohesiveness (0.691) and specific volume (1.86 cm^3/g). A formulation with 40 % of the wheat flour replaced with yacon meal, 6 % replaced with inulin and containing 126 mL of water showed similar values to the optimised formulation for the three parameters mentioned, but, in addition, it had a greater content of fructooligosaccharides and inulin. Both formulations may give useful functional foods with physical parameters comparable with the control formulation. Japanese scientists are considering developing yacón as a source for purified fructan and a variety of processed products such as fermented pickles, dried tuber slices and fructose. Yacon slices and stripes retain crunchiness during cooking and have shown potential in Asian stir-fried dishes. The stems and rhizomes may also be eaten as vegetables.

Botany

The yacon is an erect perennial herb, 1.5–2.5 m tall (Plate 1). The root system is composed of 4–20 fleshy tuberous, fusiform storage roots that can reach a length of 25 cm by 10 cm in diameter (Plates 5 and 6), with an extensive system of thin fibrous roots. The aerial stems are cylindrical or subangular, hollow at maturity with few branches in most cultivars or ramified in others, densely pubescent, green to purplish. Lower leaves are broadly ovate and hastate or subhastate, connate and auriculate at the base, densely pubescent (Plate 2). Upper leaves are deltoid and hastate to

Plate 1 Yacon plant habit

Plate 4 Close-up of yacon flower

Plate 2 Close-up of yacon leaf

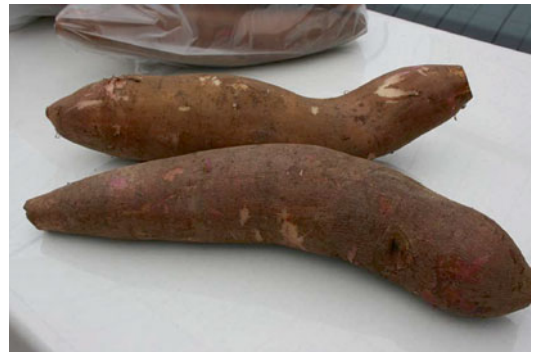

Plate 5 Yacon tuberous roots

Plate 3 Yacon inflorescences and buds

Plate 6 Close-up of yacon tuberous root

33 cm long by 22 cm wide, dentate, densely pubescent, with lateral wings, connate and auriculate at the base. Lower and upper epidermises have trichomes (0.8–1.5 mm long, 0.05 mm diameter) and glands. Inflorescences are terminal, composed of 1–5 axes, each one with 3 capitula, peduncles densely pilose (Plate 3). Phyllaries 5, uniseriate and ovate, 15 mm long, 10 mm wide. Flowers are yellow to bright orange; ray flowers 13–15, with 2- or 3-toothed ligule, to 12 mm long by 7 mm broad, pistillate; and disc flowers about 60 or more, about 7 mm long, pubescent staminate (Plate 4). Immature cypselas are purple and turn dark brown or black at maturity.

Nutritive/Medicinal Properties

Root Phytochemicals

Members of the Compositae like Jerusalem artichoke and yacon had been found to the richest plant source of fructooligosaccharides (FOCs) like 1-kestose (1-kestriose, GF_2), nystose (1,1-kestotetraose; GF_3) and 1^F-β-fructofuranosylnystose (1,1,1-kestopentaose; GF_4) (Campbell et al. 1997; Dumitriu 2004).

The bulk of yacon tuber dry matter had been reported to contain as storage compound mainly fructans of low polymerisation, i.e. fructooligosaccharides (FOSs) with inulin-type structures, i.e. β(1→2) fructofuranosyl saccharose, free sugars – low glucose, sucrose and fructose content (Ohyama et al. 1990; Asami et al. 1991; Wei et al. 1991).

The oligosaccharides in yacon tuberous roots were confirmed to be β-(2→1) fructooligosaccharides (FOSs) with terminal sucrose (inulin-type oligofructans) (Goto et al. 1995). The major FOSs found in yacon included 1-kestose, and nystose, similar to those found in *Helianthus tuberosus* (Choque Delgado et al. 2010; Ohyama et al. 1990; Moscatto et al. 2006). FOSs are sweet tasting and are considered to be indigestible by the human small intestine and serve mainly as dietetic sweeteners. The relative proportions of oligofructans and free sugars fluctuated significantly during the growing period and after harvesting (Asami et al. 1991; Fukai et al. 1995). Asami et al. (1991) reported that oligofructans accounted for 67 % of the total carbohydrates in fresh yacon tubers, while Ohyama et al. (1990) found only 20 % oligofructans, 3–22 % fructose and glucose 2–5 % of root dry matter in stored tubers. Ohyama et al. (1990) reported the following saccharides (mg/g DW) in yacon tubers stored for 96 days after harvest: fructose (350.1 mg), glucose (158.3 mg), sucrose (74.5 mg), glukosylfructose (GF) GF_2 (1-kestose) (60.1 mg), GF_3 (nystose) (47.4 mg), GF_4 (33.6 mg), GF_5 (20.6 mg), GF_6 (15.8 mg), GF_7 (12.7 mg), GF_8 (9.6 mg), GF_9 (6.6 mg) and inulin (13.5 mg). Itaya et al. (2002) reported that yacon tubers accumulated over 60 % of inulin-type β (1→2) fructans mainly GF_2–GF_{16} oligomers. Variations in the concentration of such carbohydrates and in the chain length of fructans may occur during plant growth and after harvesting. Tuberous yacon roots were found to contain highest amounts of oligofructans (GF2,GF3,Gf4), and lower stem and tubers also had high content, but leaves contained small amount; highest sucrose–sucrose fructosyl transferase (SST) activity was detected in the lower stems, and invertase activity was high in the leaves and upper stem (Fukai et al. 1993). In the lower stem, tubers and tuberous roots invertase activity was low, but SST activity was detected in these plant parts. Tubers had the highest degree of polymerisation of oligofructans. Asami et al. (1992) found that tubers and tuberous roots harvested in late fall contained about 57 and 66 % DM basis respectively of oligofructans; however, tuber, tuberous roots and shoots contained only a small amount of inulin and starch.

Calvino (1940) reported the following nutrient composition of fresh and dry yacon tubers, respectively: water (69.5 %, –), ash (2.4 %, 6.71 %), proteins (2.22 %, 7.31 %), lipids (0.13 %, 0.43 %), fibre (1.75 %, 5.73 %) and saccharides (19.67 %, 67.53 %). Chemical composition of 10 yacon accessions per kg of root fresh matter was determined as dry matter 98–136 g, total carbohydrates 89–127 g, fructans 31–89 g, DP (degree of polymerisation) 3.6–4.3, total free sugars 18–42 g, free glucose 2.3–5.9 g, free fructose 3.9–21.1 g, free sucrose 10–19 g, total fructose/total glucose ratio 1.95–2.86, °Brix 9.0–12.6, protein 2.7–4.9 g, fibre 3.1–4.1 g, fat 112–464 mg, energy 148–224 kcal, ash 4,275–6,014 mg, Ca 56–131 mg, P 182–309 mg and K 1,843–2,936 mg (Hermann et al. 1998). Hermann et al. (1998) reported that yacon fructans are of low molecular mass. Grau and Rea (1997) reported the following nutrient composition of yacon tubers on a fresh weight basis compiled from various sources: water 93–70 %, ash 0.3–0.2 %, fat 0.1–0.2 %, fibre 0.3–01.7 %, minerals (mg/g) Ca 23 mg, P 21 mg, Fe 0.3 mg, vitamins (mg/g) retinol 10 mg, carotene 0.08 mg, thiamine 0.01 mg, riboflavin 0.1 mg, niacin 0.33 mg and

ascorbic acid 13 mg. The New Zealand genotype had highest fructose (217 g/kg DM) but lower in inulin content. Valentová and Ulrichová (2003) reported yacon tuber to contain 70–93 % water, 0.4–2.0 % proteins, 12.5 % saccharides, 0.1–0.3 % lipids, 0.3–2.0 % ash, 0.3–1.7 % fibre and mg/100 g of Ca 23 mg, P 21 mg, Fe 0.3 mg, Cu 0.96 mg, Mn 0.54 mg, Zn 0.67 mg, retinol 10 mg, thiamine 0.01 mg, ascorbate 13.1 mg, carotene mg, riboflavin 0.11 mg and niacin 0.34 mg.

Moscatto et al. (2006) reported the following chemical composition of yacon root: moisture 7.49 %, protein 6.48 %, lipid 0.31 %, ash 3.56, carbohydrate 82.16 %, fructose 4.13 %, glucose 1.96 %,, sucrose 3.25 %, 1-kestose (GF_2) 8.19 % and nystose (GF_3) 5.36 %. Lobo et al. (2007) reported the following chemical composition of yacon flour g/100 g: protein 2.64 g, lipid 0.61 g, ash 3.85 g, insoluble fibre 7.85 g, soluble fibre 3.36 g, Ca 0.83 mg/g, Mg 0.62 mg/g, fructose 13.51 g, glucose 8.97 g, sucrose 13.42 g and FOS/fructans 55.33 g. Choque Delgado et al. (2012) reported the following chemical composition of yacon root: moisture 8.02 %, protein 2.45 %, lipid 0.87 %, ash 2.53 %, insoluble fibre 3.46 %, carbohydrate 86.13 %, fructose 14.10 %, glucose 7.30 %, sucrose 10.5 %, FOS/fructans 34.31 %, 1-kestose (GF2) 13.99, nystose (GF3) 13.72 % and fructofuranosyl-nistose (GF4) 6.59 %.

Lachman et al. (2007) found considerable variation among yacon ecotypes from New Zealand, Bolivia, Ecuador and Germany in total polyphenolics (TP) of plant biomass (tuberous roots, rhizomes and leaves) (34.94–68.49 mg/g), inulin (nd-289 g/kg DM), saccharose (nd-30.4 g/kg DM), glucose (nd-103 g/kg DM) and fructose (nd-217 g/kg DM). The highest TP content was found in the rhizomes and lowest in tuberous roots. The New Zealand genotype had highest TP content (68.49 mg/g DM) in the biomass. The approximate proportion of TP in the tuberous roots, leaves and rhizomes was 1:1.4:3.3.

Earlier, Lachman et al. (2004) reported considerable differences among the ecotypes were observed in their inulin and fructose concentrations (141–289 mg/kg d.m. and 195–217 mg/kg d.m., resp.), but no differences were found in glucose and saccharose concentrations. The concentrations of all saccharides were significantly influenced by the year of cultivation. Tubers contained much higher levels of inulin (179 g/kg d.m.) and fructose (193 g/kg d.m.) than rhizomes. No significant differences were found for saccharose (higher in rhizomes) and glucose (lower in rhizomes). Inulin and fructose concentrations in the upper and lower parts of tubers were inversely proportional. Inulin concentration decreased by 48.7 %, and fructose, glucose and saccharose concentrations increased by 9.97 %, 31.4 % and 12.9 %, respectively, during the storage (140 days, 10 °C, 75 % relative humidity).

Graefe et al. (2004) found that after a 6-day shade, storage oligofructans (fructooligosaccharides, FOSs) in yacon root concentrations were smaller at the lower (36–48 % of DM) than at the higher altitude (39–58 % of DM). After 12 days, FOS concentrations were nearly equal at both sites (27–39 % of DM). The concentration of free sugars (fructose, glucose, sucrose) increased accordingly from 29–34 to 48–52 %. During the 6-day sun-drying experiment, FOS concentrations decreased from 50–62 to 29–44 % and free sugars increased from 29–34 to 45–51 %. The results indicate that partial hydrolysis of oligofructans starts shortly after harvest. In another study, during storage of yacon tuberous roots at low or room temperature, their fructooligosaccharides (FOSs) content significantly decreased, whereas the fructose content increased, indicating that the extent of the changes was dependent on temperature (Narai-Kanayama et al. 2006). Freezing storage at −20 °C was able to prevent the decline of FOSs in tuberous roots. They elucidated the involvement of FOS-metabolising enzymes in FOS decline during storage at 90 % relative humidity and 8 °C, and found enzyme activities acting on sucrose, both invertase (β-fructofuranosidase) and sucrose–sucrose 1-fructosyltransferase, were weakened after storage for a month (Narai-Kanayama et al. 2007). Further, the activity of fructan 1-exohydrolase acting on short FOSs such as 1-kestose (GF_2) and 1-nystose (GF_3) was higher than that of fructan/fructan 1-fructosyltransferase. These results suggested that the continuous decline in FOSs of low DP during storage was dependent mainly on the fructan 1-exohydrolase

activity. Fructans were the predominant water-soluble carbohydrate in the tubers and tuberous roots throughout the growth period of yacon (Fukai et al. 1995). The amount of fructans in the tubers increased rapidly in November and remained constant during the dormancy. While the amount of fructans in the tuberous roots increased dramatically in September, there was a significant decrease in fructan content during the period between October and March. During summer, the amount of fructan (g/plant) accumulated in each plant part was minimal despite the existence of relatively high specific activities (units/mg protein) of sucrose–sucrose fructosyltransferase and fructan–fructan fructosyltransferase in the stems, roots, tuberous roots and rhizomataceous stem (Fukai et al. 1997). In contrast, from October to December, the amount of fructan in the tuberous roots and rhizomataceous stem significantly increased along with an increase of the total activities of sucrose–sucrose fructosyltransferase and fructan–fructan fructosyltransferase. Significant variations in tuber shape, weight, content of oligofructans as well as in leaf isozymes, phenolics and relative DNA contents were found among four yacon accessions cultivated in the field (Valentová et al. 2006). A significantly higher content of beta-(2→1) oligofructans was noted in two accessions 48 and 88 compared to 6 and 60; accession 6 exhibited separate acid phosphatase and esterase isoforms and had highest content of phenolics, while accession 88 had the lowest relative DNA content. No difference in sucrose, glucose and fructose levels was observed.

The following compound were reported from the tuberous roots: inulin and inulin derivatives (Zardini 1991); chlorogenic acid and tryptophan (Yan et al. 1999); ferulic acid (Simonovska et al. 2003); two novel, water-soluble, phenolic compounds octulosonic acid derivatives with a 6,8-dioxabicyclo[3.2.1]octane skeleton structures elucidated as (1*R*,2*S*,3*S*,4*R*,5*S*,7*R*)-4-hydroxy-7-hydroxymethyl-3-[3-(3,4-dihydroxyphenyl)-1-oxo-2-propenyloxy]-6,8-dioxabicyclo[3.2.1]octan-5-carboxylic acid (4-*O*-caffeoyl-2,7-anhydro-D-glycero-β-*d*-galacto-oct-2-ulopyranosonic acid) and (1*R*,2*S*,3*R*,4*R*,5*S*,7*R*)-2,4-dihydroxy-7-hydroxymethyl-2,3-bis[3-(3,4-dihydroxyphenyl)-1-oxo-2-propenyloxy]-6,8-dioxabicyclo[3.2.1]octan-5-carboxylic acid (4,5-di-*O*-caffeoyl-2,7-anhydro-D-glycero-β-D-galacto-oct-2-ulopyranosonic acid) (Takenaka and Ono 2003); five caffeic acid derivatives, namely, chlorogenic acid (3-caffeoylquinic acid) and 3,5-dicaffeoylquinic acid, caffeic acid esters of altraric acid: 2,4- or 3,5-dicaffeoylaltraric acid, 2,5-dicaffeoylaltraric acid and 2,3,5- or 2,4,5-tricaffeoylaltraric acid (Takenaka et al. 2003) and *ent*-kaurenoic acid (Ragusa et al. 2008). Phenolic compounds, flavonoids, alkaloids, steroids, glycosides and carbohydrates were found in yacon roots (Alvarez et al. 2008). From the root cortex of four *Smallanthus* species including *S. sonchifolius*, *ent*-16-kauren-19-oic acid (kaurenoic acid) methyl ester was the main component; minor components included grandiflorenic acid methyl ester, ent-16-kauren-19-al, 16α,17-epoxy-15α-angeloyloxy-kauran-19-oic acid methyl ester and several O-acyl derivatives at C-15 or C-18 of kaurenoic acid (Coll Aráoz et al. 2010). One of the minor components, 18-isobutyroyloxy-*ent*-kaur-16-en-19-oic acid was a new kaurenoic acid derivative. Grandiflorenic acid and 15-α-angeloyloxy-16,17-α-epoxy-*ent*-16-kauren-19-oic acid were present only in *Smallanthus sonchifolius* and *Smallanthus siegesbeckius*.

Inoculation of sliced yacon tubers with *Pseudomonas cichorii* resulted in the formation of three major antifungal phytoalexins identified as 4′-hydroxy-3′-(3-methylbutanoyl)acetophenone, 4′-hydroxy-3′-(3-methyl-2-butenyl)acetophenone and 5-acetyl-2-(1-hydroxy-1-methylethyl) benzofuran (Takasugi and Masuda 1996). Polyphenol oxidase (PPO) with molecular weight of about 45,490 Da and K_m values of 0.23, 1.14, 1.34 and 5.0 mM for the substrates caffeic acid, chlorogenic acid, 4-methylcatechol and catechol, respectively, was extruded from yacon roots (Neves and da Silva 2007). The optimum pH varied from 5.0 to 6.6, depending on substrate. PPO activity was inhibited by various phenolic and nonphenolic compounds. Sucrose, maltose, glucose, fructose and trehalose at high concentrations appeared to protect yacon PPO against thermal inactivation at 75 and 80 °C.

Powdered yacon pulp showed a laminar-type structure, and good encapsulation of the yacon juice by starch was observed in the samples of concentrated juice powder (Lago et al. 2012). Powdered yacon pulp before drying and after drying at 70 °C was found to contain (g/100 g dm), respectively, 3.15 g, 2.70 g inulin, 10.98 g, 12.82 g glucose and 4.30 g, 9.44 g fructose, while starch-encapsulated yacon juice before drying and after drying at 70 °C contained (g/100 g dm), respectively, 1.07 g, 0.90 g inulin, 3.30 g, 3.51 g glucose and 2.99 g, 3.55 g fructose (Lago et al. 2012). The process used to dry starch-encapsulated yacon juice and yacon pulp indicated that the higher the drying air temperature, the shorter the time taken to reach equilibrium. All dehydrated products presented water activity values below 0.3, indicating the stability of the powders.

In addition to prebiotics, fructooligosaccharides (FOSs) and inulin, yacon had been found to contain flavonoids, phenolic acids and tryptophan, which exhibited antioxidant, anti-inflammatory, antimicrobial and anticancer activities (Choque Delgado et al. 2013). The consumption of FOS and inulin had been reported to improve the growth of bifidobacteria in the colon, enhanced mineral absorption and gastrointestinal metabolism and to play role in the regulation of serum cholesterol (Choque Delgado et al. 2010, 2013). Additionally, studies reported that the consumption of these prebiotics promoted a positive modulation of the immune system, improving resistance to infections and antimicrobial activity as well as attenuating allergic reactions and cancer in experimental models.

Leaf and Stem Phytochemicals

Valentová and Ulrichová (2003) reported yacon leaf to contain 10.47 % water, 21.48 % proteins, 4.2 % lipids, 12.52 % ash, 11.63 % fibre and mg/100 g of Ca 1,805 mg, P 543 mg, Fe 10.82 mg, Cu <0.5 mg, Mn 3.07 mg and Zn 6.2 mg. They reported yacon stem to contain 9.73 % proteins, 1.98 % lipids, 9.6 % ash, 23.82 % fibre and mg/100 g of Ca 967 mg, P 415 mg, Fe 7.29 mg, Cu <0.5 mg, Mn <0.5 mg and Zn 2.93 mg.

The following compounds were found in the leaves: an antifungal melampolide, 8-angeloyl-1(10),4,11(13)-germacuratrien-12,6-olid-14-oic acid methyl ester, named sonchifolin, and three known melampolides, polymatin B, uvedalin and enhydrin (Inoue et al. 1995); protocatechuic (2.5 and 0.12 mg/g), chlorogenic (9.9 and 1.7 mg/g), caffeic (14.7 and 0.09 mg/g) and ferulic (traces) acids (Valentová et al. 2003); six sesquiterpene lactones, 8β-tigloyloxymelampolid-14-oic acid methyl ester, 8β-methacryloyloxymelampolid-14-oic acid methyl ester, sonchifolin, uvedalin, enhydrin and fluctuanin (Lin et al. 2003); chlorogenic, caffeic and ferulic acid, isomers of dicaffeoylquinic acid, an unidentified derivative of chlorogenic acid, flavonoid quercetin and an unidentified flavonoid (Simonovska et al. 2003); four diterpenoids named smaditerpenic acid A–D and five known compounds (Dou et al. 2008b); *ent*-kaurane-3β,16β,17,18-tertol, 3*R*,7*E*-9-butoxyl-megastigma-3-ol-3-*O*-β-D-glucopyranoside, 3*S*,5*R*,6*Z*-megastigma-6-en-3,5,8,9-tertol and five known compounds octacosanol, 3′,4′,5-trihydroxy-3,7-dimethoxyflavone, 3,4-dihydroxybenzaldehyde, isorhamnetin and *ent*-kaurane-3β,16β,17-triol (Qiu et al. 2008); *ent*-kaurenoic acid (Ragusa et al. 2008); smallanthaditerpenic acid A, smallanthaditerpenic acid B, smallanthaditerpenic acid C, smallanthaditerpenic acid D, *ent* -kaurane-3β, 16β, 17, 19-tetrol and *ent*-kaurane-16β, 17, 18, 19-tetrol (Dou et al. 2008a); gallic acid, β-sitosterol, behenic acid, kaempferol, quercetin, vanillic acid and hexadecanoic acid (Xie et al. 2008); two new melampolide-type sesquiterpene lactones, 8β-epoxyangeloyloxy-9α-ethoxy-14-oxo-acanthospermolide and 8β-angeloyloxy-9α-ethoxy-14-oxo-acanthospermolide along with 11 known melampolide allo-schkuhriolide, enhydrin, polymatin A, fluctuanin, 8β-angeloyloxy-9α-acetoxy-14-oxo-acanthospermolide, 8β-angeloyloxy-14-oxo-acanthospermolide, 8β-methacryloyloxymelampolid-14-oic acid methyl ester, uvedalin, polymatin B, 8β-tigloyloxymelampolid-14-oic acid methyl ester and sonchifolin (Hong et al. 2008); octadecatrienoic acid elucidated as 13(*R*)-hydroxy-octadeca-(9*E*,11*E*,15*Z*)-trienoic acid and a benzyl glycoside elucidated as benzyl alcohol 7-*O*-α-L-arabinopyranosyl(1″→2′)-β-D-

glucopyranoside, along with a known compound 13(*R*)-hydroxy-octadeca-(9*Z*,11*E*,15*Z*)-trienoic acid (Xiang et al. 2009); smallanthaditerpenic acids A, B, C and D and chlorogenic and caffeic acids (Xiang et al. 2010b); two diterpenes, named *ent*-kaurane-3β,16β,17, 19-tetrol and *ent*-kaurane-16β,17,18,19-tetrol (Dou et al. 2010); a hexenol glycoside elucidated as *Z*-hex-3-en-1-ol *O*-α-L-arabinopyransyl (1″→2′)-β-D-glucopyranoside and two known compounds *ent*-15β-hydroxy-kaur-16-en-19-oic acid and ent-18-hydroxy-kaur-16-en-19-oic acid (Xiang et al. 2010a); caffeic, chlorogenic and three dicaffeoylquinic acids and enhydrin (Genta et al. 2010); two acyclic diterpenoids, smaditerpenic acid E and F, along with 19 melampolide-type sesquiterpene lactones (Mercado et al. 2010); enhydrin, polymatin B and allo-schkuhriolide (Choi et al. 2010); and enhydrin, uvedalin and sonchifolin (Siriwan et al. 2011).

The dried yacon leaves were found to contain a total of 0.97 % of the antidiabetic sesquiterpene lactone enhydrin 1 and the glandular trichome extract contained 0.07 mg/mL (Schorr and Da Costa 2005). The following phenolic acids gallic acid, protocatechuic acid, chlorogenic acid, caffeic acid and ferulic acid were detected in the ethyl acetate extract of dried yacon leaves and in the leaf aqueous decoction, and aqueous tea infusion gallic acid and ferulic acid were not detected (Jirovský et al. 2003).

Yacon glandular trichomes and leaves were found to be rich in *ent*-kaurenic acid (*ent*-kaur-en-19-oic acid) and to contain a kaurene derivative 15-α-angeloyloxy- *ent*-kaur-en-19-oic acid 16-epoxide and 2 known angeloyloxykaurenic acids *ent*-kaur-16-en-19-oic acid 15 angeloyloxy ester and 18-angeloyloxy- *ent*-kaur-16-en-19-oic acid (Kakuta et al. 1992). Trichomes were found to accumulate sesquiterpene lactones uvedalin and enhydrin and their epoxyangelate esters (Lopes et al. 2013). The major compounds found in yacon leaf essential oil were β-pinene, caryophyllene and γ-cadinene (Adam et al. 2005).

Calvino (1940) reported the nutrient composition of fresh and dry yacon leaves respectively as follows: water (83.2 %,-), ash (2.68 %, 15.98 %), proteins (2.87 %, 17.12 %), lipids (1.24 %, 7.40 %), fibre (1.68 %, 10.04 %) and saccharides (1.44 %, 8.58 %).

Antioxidant Activity

Yacon root exhibited 1, 1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity, and two major antioxidants chlorogenic acid and tryptophan were isolated from the methanol root extract (Yan et al. 1999). The phenolic acids, chlorogenic, caffeic and ferulic acid isolated from the crude extract of yacon leaves gave significant contribution to the radical scavenging activity detected directly on the TLC plate sprayed with 1,1-diphenyl-2-picrylhydrazyl (DPPH) (Simonovska et al. 2003). Protocatechuic (2.5 and 0.12 mg/g), chlorogenic (9.9 and 1.7 mg/g), caffeic (14.7 and 0.09 mg/g) and ferulic (traces) acids were determined in the two fractions of yacon leaves (Valentová et al. 2003). Both fractions showed potent antioxidant activity in DPPH (IC_{50} = 16.1 and 24.3 mg/mL) and xanthine/XOD superoxide radical scavenging (42.0 and 34.3 SOD equivalents (U/mg)) tests, they inhibited the lipoperoxidation of rat liver subcellular membranes and they protected rat hepatocytes against oxidative injury. Yacon leaf aqueous extracts exhibited DPPH (IC_{50} 16.14–33.39 μg/mL) and HO* scavenging activities (IC_{50} 4.49–6.51 mg/mL) in-vitro (Valentová et al. 2005). The extracts did not scavenge phenylglyoxylic ketyl radicals, but they retarded their formation. The extracts' total phenolic content was 10.7–24.6 %. In the xanthine/xanthine oxidase superoxide radical generating system, the extracts' activities were 26.10–37.67 superoxide dismutase equivalents/mg. As one of the extracts displayed xanthine oxidase inhibitory activity, the effect of the extracts on a nonenzymatically generated superoxide was determined (IC_{50} 7.36–21.01 μg/mL). The extracts inhibited *t*-butyl hydroperoxide-induced lipoperoxidation of microsomal and mitochondrial membranes (IC_{50} 22.15–465.3 μg/mL). All 13 melampolides isolated from leaves inhibited lipopolysaccharide (LPS)-induced nitric oxide production in murine macrophage RAW 264.7 cells (Hong et al. 2008).

The content of total phenol was the highest by 45.53 % in ethyl acetate fraction of yacon extract (Min et al. 2008), and the results of electron donating abilities were 65.20 % (100 μg/mL), 91.81 % (500 μg/mL) and 95.06 % (1,000 μg/mL), and those of nitrite scavenging abilities were 11.71 % (100 μg/mL), 36.81 % (500 μg/mL) and 59.70 % (1,000 μg/mL) in ethyl acetate fraction, which were higher concentration than the control group. Xanthine oxidase inhibitory activities were 23.74 % (100 μg/mL) and 43.41 % (500 μg/mL) which were higher than the control group.

Antihyperglycemic/Hypoglycaemic Activity

In-Vitro Studies

Ent-kaurenoic acid, dissolved in dimethyl sulfoxide, exhibited potential antidiabetes and antitoxicity activity (Ragusa et al. 2008). Smallanthaditerpenic acids A, B, C and D isolated from yacon leaves exhibited inhibitory effect on α-glucosidase and their IC_{50} were determined to be 0.48 mg/mL, 0.59 mg/mL, 1.00 mg/mL and 1.17 mg/mL, respectively (Xiang et al. 2010b).

Yacon leaf extract was found to show potent antidiabetic activity (Dou et al. 2008a, 2010).

Animal Studies

Ten per cent yacon leaf decoction produced a significant decrease in plasma glucose levels in normal rats when administered by intraperitoneal injection or gastric tube (Aybar et al. 2001). In a glucose tolerance test, a single administration of 10 % yacon leaf decoction lowered the plasma glucose levels in normal rats. In contrast, a single oral or intraperitoneal administration of yacon leaf decoction produced no effect on the plasma glucose levels of streptozotocin-induced diabetic rats. However, the administration of 2 % yacon tea ad libitum instead of water for 30 days produced a significant hypoglycaemic effect on streptozotocin-induced diabetic rats. After 30 days of yacon tea administration, diabetic rats showed improved body (plasma glucose, plasma insulin levels, body weight) and renal parameters (kidney weight, kidney to body weight ratio, creatinine clearance, urinary albumin excretion) in comparison with the diabetic controls. Their results suggested that yacon leaf water extract produced an increase in plasma insulin concentration. The potential of yacon tubers to treat hyperglycaemia, kidney problems and for skin rejuvenation and the antihyperglycaemic and cytoprotective activity of its leaves appeared to be related mostly to its oligofructan and phenolic content, respectively (Valentová and Ulrichová 2003). Aqueous leaf extracts and fractions tested exhibited strong protective effect against oxidative damage induced by tert-butyl hydroperoxide (t-BH) and allyl alcohol to rat hepatocyte primary cultures in concentrations ranging from 1 to 1,000 μg/mL and reduced hepatic glucose production via gluconeogenesis and glycogenolysis at 1,000 μg/mL (Valentová et al. 2004). Moreover, the effects of the organic fractions (200 and 250 μg/mL) and, to a lesser extent, the tea infusion (500 μg/mL) on rat cytochrome CYP2B and CYP2E mRNA expression were comparable to those observed with insulin. The combination of radical scavenging, cytoprotective and antihyperglycaemic activity suggested the potential for yacon leaves to be used for prevention and treatment of chronic diseases involving oxidative stress, particularly diabetes. Aqueous yacon leaf extract reduced blood glucose and cholesterol of KKAy mice 6 weeks after repeated administration but did not affect blood glucose in normal mice (Miura et al. 2004; Miura 2007). Yacon also improved hyperglycaemia after glucose tolerance. Yacon also tended to decrease blood glucose in an insulin tolerance test. Results showed yacon to be useful for hyperglycaemia and hyperlipidemia of type 2 diabetes.

Treatment with yacon leaf ethanol extract for 14 days reduced glycemia in diabetic and nondiabetic rats, but this reduction was not observed in animals treated with cold or hot yacon leaf extracts (Baroni et al. 2008). Additionally, yacon leaf ethanol extract restored the activity of the plasma enzymes (AST, ALT, ALP) that were altered and improved weight gain in the diabetic animals. The results suggested that the effectiveness of the yacon extracts was related to the

method of preparation and to the time of treatment rather than to reduction of food intake or to interference of the extract with intestinal absorption of carbohydrates. Hypoglycaemic activity was observed in normoglycaemic mice orally administered with the aqueous yacon leaf tea extract, alloxan-induced diabetic mice orally administered with ent-kaurenoic acid (from yacon leaves) and normoglycaemic mice intraperitoneally administered with ent-kaurenoic acid (Raga et al. 2010). The methanol, butanol and chloroform yacon leaf extracts showed effective hypoglycaemic activity at minimum doses of 50, 10 and 20 mg/kg body weight, respectively (Genta et al. 2010). Oral administration of a single dose of each extract produced a slight lowering effect in the fasting blood glucose level of normal healthy rats, whereas each extract attenuated significantly the hyperglycaemic peak after food ingestion in transiently hyperglycaemic and streptozotocin (STZ) diabetic rats. Daily administration of each extract for 8 weeks produced an effective glycaemic control in diabetic animals with an increase in the plasma insulin level. Phytochemical analysis of the most active fraction, the butanol extract, showed that caffeic, chlorogenic and three dicaffeoylquinic acids were significant components. Additionally, enhydrin, the major sesquiterpene lactone of yacon leaves, was also effective to reduce postprandial glucose and useful in the treatment of diabetic animals (minimum dose: 0.8 mg/kg body weight). Administration of yacon leaf decoction for 4 weeks significantly decreased high blood glucose level in streptozotocin-induced diabetic rats and improved insulin production (Honoré et al. 2012). Diabetic-dependent alterations in urinary albumin excretion, creatinine clearance, kidney hypertrophy and basement membrane thickening were attenuated by yacon decoction. These findings were associated with a marked decrease in TGF-β1/Smad2/3 signalling and expression of molecular markers of diabetic nephropathy such as collagen IV, laminin-1, fibronectin and collagen III in the yacon-treated group compared to control diabetic group. The results suggested yacon leaf decoction to be a protective agent against renal damage in diabetic nephropathy, whose action can be mediated by TGF-β/Smads signals.

Oral administration of yacon tuber extract (200 mg/kg) and its active constituent, chlorogenic acid (CGA) (10 mg/kg) for 6 weeks produced a significant hypoglycaemic effect in streptozotocin-induced diabetic rats (Park et al. 2009). Yacon and CGA-treated rats exhibited significantly decreased plasma glucose surge during the glucose tolerance test. Total cholesterol (TC) and triglyceride (TG) concentrations were significantly decreased by 33 % and 49 %, respectively, in yacon-treated rats significantly decreased by 26 % and 41 %, respectively, in CGA-treated rats. In the DPPH assay, free radical scavenging activity of CGA was similar to that of vitamin E, a positive control. This study suggested that yacon tuber extract and its constituent, CGA, may be a useful option for management of hyperglycaemia and diabetic nephropathy.

The aqueous yacon tuberous root extract decreased water and food intake, glycaemia, total cholesterol, VLDL-c, LDL-c and triacylglycerol levels in diabetic rats (Oliveira et al. 2013). Yacon treatment normalised alanine aminotransferase (ALT) but had no effect on lactate dehydrogenase activity. The results suggested that yacon tuber extract sufficient for controlling water and food consumption, hyperglycaemia and dyslipidaemia and promote the reduction of the ALT, suggesting a hepatoprotective effect in rats with streptozotocin-induced diabetes mellitus. In the basal state, yacon feeding of male Zucker fa/fa rats for 5 weeks had an effect of lowering fasting glucose levels from 184.1 to 167.8 mg. dl as well as basal hepatic glucose output (HGO) from 9.9 to 7.4 mg/kg/minutes (Satoh et al. 2013). During the clamp studies, the glucose infusion rate required to maintain euglycemia was increased by 12.3 % in yacon-fed rat. The insulin suppression of HGO was also increased in yacon-fed rats compared with control rats. Consistent with the clamp data, the insulin-stimulated phosphorylation of Akt was significantly enhanced in liver but not in skeletal muscle. Further, tribbles 3 (Trb3) expression, a negative regulator of Akt activity, was markedly reduced in the liver of yacon-fed rats compared with control rats. The results indicated that the

effect of yacon feeding in reducing blood glucose was likely due to its beneficial effects on hepatic insulin sensitivity in the insulin resistant state.

Antiatherogenic/Antihyperlipidemic Activities

Animal Studies

Administration of fructooligosaccharides-rich yacon flour to streptozotocin-induced diabetic Wistar rats for 90 days significantly decreased fasting plasma triacylglycerol and very low-density lipoprotein levels and did not significantly alter the body weight of animals throughout the experimental period (Habib et al. 2011). Yacon treatment was also able to protect the diabetic rats of the postprandial peak of plasma triacylglycerol. Yacon-supplemented rats showed an increased insulin-positive pancreatic cell mass distributed in small cell clusters within the exocrine parenchyma. Glucagon like peptide-1 content in the cecum was significantly higher in diabetic rats treated with a diet supplemented with yacon flour compared with untreated diabetic animals. The results suggested that yacon root flour rich in fructooligosaccharides could be well positioned as a nutraceutical product with beneficial effects on diabetes-associated hyperlipidemia. In another animal study, serum ALT, AST, ALP and LDH activities elevated by a high fat–high cholesterol diet were significantly decreased by Yacon powder administration in obese male Sprague-Dawley rats (Kim et al. 2010). Levels of serum total cholesterol, LDL-cholesterol, atherogenic index and cardiac risk factor showed a decreasing tendency in the Yacon powder-fed groups compared with high fat-high cholesterol diet group (HFC) group. The serum HDL-cholesterol level decreased in the HFC group and markedly increased in the Yacon powder-fed groups. Levels of total cholesterol and triglyceride in liver and adipose tissues were lower in Yacon powder-administered groups than those in HFC group. The results suggested that Yacon powder may improve lipid metabolism of serum, liver and adipose tissue and potentially reduce lipid storage.

Clinical Studies

In a 120-day double-blind placebo-controlled study of obese and slightly dyslipidemic premenopausal women, daily consumption of yacon syrup equivalent to 0.14 g fructooligosaccharides/kg/day produced a significant decrease in body weight, waist circumference and body mass index (Genta et al. 2009). Additionally, decrease in fasting serum insulin and homeostasis model assessment index was observed. The results suggested that long-term consumption of yacon root produced beneficial health effects on obese premenopausal women with insulin resistance.

In a randomised placebo-controlled 90-day study of patients suffering from the metabolic syndrome, the combination silymarin + yacon appeared to be promising as a nutraceutical in the prevention of diseases with a proatherogenic lipoprotein profile and liver steatosis (Valentová et al. 2008). No adverse effects were found in volunteers using silymarin (0.8 g/day), silymarin + yacon (0.8+2.4 g/day) and silymarin + maca (0.6+0.2 g/day).

Anticancer Activity

The hexane fraction of yacon extract had the highest growth inhibitory activities for human gastric cancer SNU-1 cells of 23.75 % (10 μg/mL), 34.67 % (50 μg/mL) and 54.21 % (100 μg/mL) (Min et al. 2008). The hexane fraction demonstrated high growth inhibitory activities by 41.38 % (10 μg/mL), 50.53 % (50 μg/mL) and 60.91 % (100 μg/mL) and butanol fraction had 17.05 % (10 μg/mL), 43.87 % (50 μg/mL) and 62.99 % (100 μg/mL) for cervical cancer HeLa cells. Enhydrin, uvedalin and sonchifolin form yacon leaves in doses of 0.22–10 μM inhibited cervical cancer cell proliferation and induced apoptosis in both a dose- and time-dependent fashion (Siriwan et al. 2011). The apoptotic effect was associated with caspase-3/7 activation and NF-κB inhibition. Enhydrin possessing two epoxide units was found to be the most cytotoxic compound.

Consumption of yacon root extract was found to have a protective effect on colon carcinogenesis induced by 1,2-dimethylhydrazine (DMH) in male Wistar rats (de Moura et al. 2012). At week 20, a

significant reduction in number and multiplicity of aberrant crypt foci and in number of invasive adenocarcinomas was observed in the groups orally treated with 1.0 % yacon or the synbiotic formulation (1.0 % yacon plus *Lactobacillus casei* at 2.5×10^{10} CFU per g diet). Tumour multiplicity (noninvasive plus invasive) was significantly lower in the group fed synbiotic formulation. A significant reduction in cell proliferation in colonic crypts and tumours and short chain fatty acids caecal contents was observed in the groups orally treated with 1.0 % yacon or the synbiotic formulation.

Antimicrobial Activity

Sonchifolin isolated from yacon leaf exhibited the highest fungicidal activity against *Pyricularia oryzae*, a fungus causing rice blast disease, and the ED_{50} value for the spore germination was 22 ppm (Inoue et al. 1995). Aqueous yacon leaf extract at all concentrations tested induced inhibition of aflatoxin B1 production by *Aspergillus flavus* in-vitro (Pinto et al. 2001). The aqueous extract showed in-vitro cytotoxicity to Vero cells only at concentrations above 500 µg/mL. The sesquiterpene lactone, 8β-methacryloyloxymelampolid-14-oic acid methyl ester, isolated from yacon leaves, exhibited potent antimicrobial activity against *Bacillus subtilis* and *Pyricularia oryzae*, while 8β-tigloyloxymelampolid-14-oic acid methyl ester showed lower activity (Lin et al. 2003). Fluctuanin exhibited the strongest antibacterial activity against *B. subtilis* among the six sesquiterpene lactones isolated.

Ent-kaurenoic acid showed low antimicrobial activities against *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Candida albicans* and *Trichophyton mentagrophytes*, but was found to be inactive against *Bacillus subtilis* and *Aspergillus niger* (Ragusa et al. 2008). Under light illumination at 4,000 lux for 18 hours, the n-hexane fraction of yacon leaf methanol extract showed antibacterial effect against six strains of methicillin-resistant *Staphylococcus aure*us (MRSA) and one standard methicillin-susceptible *S. aureus* (MSSA) with a MIC of 15.6 µg/mL (Joung et al. 2010). No activity was detected in the absence of light. The hexane leaf fraction mixed with ampicillin or oxacillin showed a synergistic effect under similar illumination with all fractional inhibitory concentration values being below 0.5. These results suggest that only enhydrin from yacon leaves showed good in-vitro antibacterial activity against all tested strains of methicillin-resistant *Staphylococcus aureus* (MIC = 125–500 µg/mL), while polymatin B and allo-schkuhriolide did not (Choi et al. 2010).

Ent-kaurenoic acid from the dichloromethane extract of yacon leaves was found to be active *Staphylococcus aureus*, *Staphylococcus epidermidis* and *Bacillus subtilis* at the lowest concentration of 1,000 µg/L, while it was active against the fungus *Trichophyton rubrum* at 10,000 µg/L in the disc diffusion method (Padla et al. 2012). No inhibitory activity was observed against *Candida albicans*, *Epidermophyton floccosum* and all the Gram-negative test strains, *Escherichia coli*, *Enterobacter aerogenes*, *Klebsiella pneumoniae* and *Pseudomonas aeruginosa*. Results of the broth dilution MIC determination revealed that *ent*-kaurenoic acid exhibited moderate activity against *S. aureus* and *S. epidermidis* with MIC values of 125 µg/mL and 250 µg/mL, respectively, and weak activity against *B. subtilis* with a MIC of 1,000 µg/mL.

Yacon flour administration to BALB/c mice had a protective effect against enteric infection caused by a strain of *Salmonella enteritidis* serovar *typhimurium* (*S. typhimurium*) from 15 to 30 days of treatment (Velez et al. 2013). A peak of total secretory IgA production in mice without translocation of the pathogen was observed for these periods. Longer periods (45 days) of administration had no protective effect. Therefore, yacon could prevent enteric infection caused by *S. typhimurium* when given up to 30 days; this effect would be mediated by enhancing nonspecific immunity, such as total S-IgA, that improved the immunological intestinal barrier.

Spermatogenic Activity

After administering yacon tuber extract or its constituent, chlorogenic acid, to rats for 5 weeks,

numbers of sperm in epididymis were increased by 34 % and 20 %, respectively, and significantly inhibited effect of testosterone degradation in rat liver homogenate (Park and Han 2013). Yacon tuber extract and ferulic acid (another constituent) also increased sperm numbers by 43 % and 37 %, respectively, in rats. The results suggested the possibility of yacon as ameliorable agents of infertility by sperm deficiency and late onset hypogonadism syndrome with low level of testosterone.

Prebiotic Activity

Yacon being rich in fructooligosaccharides (FOSs) had been reported to confer another health benefit as studies had shown that they stimulated the growth of bifidobacteria in the human colon to suppress putrefactive pathogens and to reduce cholesterol levels (Hermann et al. 1998). The consumption of yacon FOS and inulin was reported to improve the growth of bifidobacteria in the colon, enhance mineral absorption and gastrointestinal metabolism and play a role in the regulation of serum cholesterol (Choque Delgado et al. 2013). Further, literature reported that the consumption of these prebiotics promoted a positive modulation of the immune system, improving resistance to infections and allergic reactions.

Yacon root fructooligosaccharides was found to be a potential novel source of prebiotics (Pedreschi et al. 2003). Their study found that *Lactobacillus acidophilus*, *Lactobacillus plantarum* and *Bifidobacterium bifidum* were able to ferment yacon root fructooligosaccharides (FOSs). *L. plantarum* and *L. acidophilus* completely utilised 1-kestose molecules, while *B. bifidum* was able to utilise 1-kestose molecules as well as molecules with a higher degree of polymerisation.

Anti-inflammatory Activity

Studies in BALB/c mice showed that daily consumption of yacon root for 30 days did not exert negative effects on the immune system, helped to preserve an anti-inflammatory state in phagocytic cells by significantly reducing proinflammatory cytokine IL-1β and improved mucosal immunity by elevation of the levels of faecal IgA (Choque Delgado et al. 2012). The results suggested that consumption of yacon root possibly prevented the risks associated with autoimmune and metabolic diseases.

Bone Mineral Absorption Enhancement

Animal studies by Lobo et al. (2007) showed an important role of yacon roots in the maintenance of healthy bones. Yacon flour consumption by rats significantly resulted in a positive Ca and Mg balance, leading to higher values of bone mineral retention and biomechanical properties (peak load and stiffness) when compared to the control group. There was an increase in the depth and number of total and bifurcated crypts in rats fed yacon flour. The increased number of bifurcating crypts might be related to the higher mineral absorption caused by the enlargement of the absorbing surface in the large intestine of the animals.

In a random, double-blinded study of 50 girls and 50 boys aged 9–13, daily consumption of a combination of prebiotic short- and long-chain inulin-type fructans significantly increased calcium absorption and enhanced bone mineralisation during pubertal growth at 8 week and 1 year after supplementation (Abrams et al. 2005).

Antiparasitic Activity

The sesquiterpene lactones enhydrin (1), uvedalin (2) and polymatin B from yacon showed significant trypanocidal activity against the epimastigote forms of *Trypanosoma cruzi* with IC_{50} values of 0.84 μM (1), 1.09 μM (2) and 4.90 μM (3), respectively (Frank et al. 2013). After a 24 hour treatment with 10 μg/mL of enhydrin or uvedalin, the parasites were not able to recover their replication rate. Compounds 1 and 2 showed IC_{50} values of 33.4 μM and 25.0 μM

against *T. cruzi* trypomastigotes, while polymatin B was not active. Against the intracellular forms of *T. cruzi*, all three compounds were able to inhibit the amastigote replication with IC_{50} of 5.17 μM, 3.34 μM and 9.02 μM for 1, 2 and 3, respectively. The cytotoxicity of the compounds was evaluated in Vero cells obtaining CC_{50} values of 46.5 μM (1), 46.8 μM (2) and 147.3 μM (3). According to these results, enhydrin and uvedalin may have potentials as agents against Chagas disease.

Pharmacokinetic Studies

In a 2-week crossover design placebo-controlled, double-blind study of 16 healthy volunteers, administration of yacon significantly accelerated colonic transit (Geyer et al. 2008). Yacon was well tolerated with an excellent side effect profile. Stool frequency increased from 1.1 to 1.3 two times per day and the consistency showed a tendency for softer stools. The authors asserted that due to the low caloric content of yacon, the root could be a useful treatment in constipated diabetics or obese patients.

Toxicological Studies

In a subchronic toxicity studies, dried yacon root flour administered as a diet supplement to normal Wistar rats for 4 months was well tolerated and did not produce any negative response, toxicity or adverse nutritional effect at both intake levels (340 mg and 6,800 mg fructooligosaccharides/body used (Genta et al. 2005). Yacon root consumption showed no hypoglycaemic activity in normal rats and resulted in significantly reduced postprandial serum triacylglycerol levels in both doses assayed. Conversely, serum cholesterol reduction was not statistically significant. Caecal hypertrophy was observed in rats fed only the high dose. The results indicated lack of toxicity with yacon consumption and a certain beneficial metabolic activity in normal rats.

A repeated-dose toxicity study in Wistar rats for 90 days found that renal damage was associated with increased blood glucose levels after prolonged oral administration of the yacon leaf extract (de Oliveira et al. (2011). This observation suggested that the hypoglycaemic effect observed after treatment for 30 days in an earlier study was reversible and was likely the result of renal injury caused by the toxicity of yacon. Sesquiterpene lactones were detected in both aqueous leaf tea infusion and leaf rinse extract, suggesting that these sesquiterpene lactones were the main toxic compounds in yacon leaves.

Adverse Effects

A 55-year-old woman who developed syncope and generalised urticaria after ingesting yacon roots was reported by Yun et al. (2010). The patient had positive skin prick and intradermal tests to yacon extract. An open food challenge test was performed to confirm food anaphylaxis and was positive 10 minutes after the consumption of yacon roots.

Studies showed that Wistar rats fed fortified ultra rice with micronised ferric pyrophosphate had high iron bioavailability, but the addition of yacon flour at 7.5 % FOS reduced iron bioavailability (Della Lucia et al. 2013).

Traditional Medicinal Uses

The leaves are used in folk medicine as a medicinal tea for hypoglycaemia (Valentová et al. 2003). Owing to its high contents of fructooligosaccharides (FOSs), the yacon root is used in traditional Andean medicine as a substitute for cane sugar in diabetes and for obesity prevention (Choque Delgado et al. 2012).

Other Uses

Smallanthus sonchifolius (yacon) is a perennial plant mostly cultivated in South America, primarily for use of the tubers as a food crop and the leaves as fodder for livestock (Joung et al. 2010).

Yacon extract was found to be a good substrate to produce inulinase by yeast *Kluyveromyces marxianus* var. *bulgaricus* (Cazetta et al. 2005). The highest activity was observed at 60 °C and pH 4.0.

Comments

Yacon is commonly propagated vegetatively from its fleshy rhizome by partitioning it into 6–14 propagules. Alternatively, nodal or stem cuttings can be rooted for vegetative propagation. Sexual reproduction of yacon is difficult because of the lack of fertile botanical seeds formed.

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Tragopogon porrifolius

Scientific Name

***Tragopogon porrifolius* L.**

Synonyms

Tragopogon australis Jord., *Tragopogon porrifolius* var. *cupani* (Guss.) Fiori, *Tragopogon sinuatus* Avé-Lall.

Family

Asteraceae

Common/English Names

Common Salsify, Goatsbeard, Jerusalem Star, John-Go-To-Bed-At-Noon, Joseph's Flower, Oyster Plant, Purple Goatsbeard, Purple Salsify, Salsify, Vegetable Oyster, Vegetable Oyster Plant, White Salsify, Wild Quinine, Wild Salsify

Vernacular Names

Afrikaans: Hawerwortel
Bulgarian: Salzifi
Catalan: Barbeta, Barba De Cabra, Salsifi
Chinese: Bo Lou Men Shen, Po Lo Min Shin, Suan Ye Po Luo Men Shen
Corsican: Scorzu Bianco
Croatian: Turovet
Czech: Kozí Brada Fialová, Kozí Brada Pórolistá, Salsifis, Witte Schorseneer
Danish: Havrerod
Dutch: Blauwe Morgenster, Boksbaard, Haverwortel, Paarse Morgenster
Estonian: Aed-Piimjuur, Piimjuur
Esperanto: Tragopogo Porefolia, Tragopogo Purpura
Finnish: Kaurajuuri
French: Salsifi, Salsifis, Salsifis À Feuilles De Poireau, Salsifis Blanc, Salsifis Cultivé
Gaelic: Salsabh, Salsey
Galician: Barba Cabreira
German: Austernpflanze, Gemüse-Haferwurz, Habermark, Haferwurz, Haferwurzel, Lauchblättriger Bocksbart, Purpur-Bocksbart, Roter Bocksbart, Weiswurzel
Greek: Lagohorta, Lagolachano, Tragopogon O Proscophylos
Hebrew: Zekan Ha-Tayish, Zkan-Hataish
Hungarian: Ártifi, Kecskedin, Közönséges Bakszakáll, Saláta Bakszakáll, Szalszifi
Icelandic: Hafursrot
India: Ek Qism Ka (Hindi)
Italian: Barba Di Becco, Barba Di Becco Violetta, Salsefica, Salsefrica, Scorzonera Bianca, Scorzobianca

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Japanese: Baramonjin, Mugina Deshiko, Sarushifai, Seiyou Gobou
Korean: Seoyang Ueong
Lithuanian: Valgomasis Putelis
Macedonian: Španska Kozička, Španska Kozja Brada
Maltese: Lehjet Il-Bodbod
Mongolian: Jamaan Sakhal
Norwegian: Rotgeitskjegg, Geitskjegg, Havrerot
Polish: Kozibród Porolistny, Salsefia
Portuguese: Barba-De-Bode, Cercifi, Salsi Branco, Cersefi
Romanian: Barba Caprei
Russian: Kozloborodnik, Sal, Sifi
Serbian: Turovet
Slovašcina: Kozja Brada Porovolistna, Porovolistna Kozja Brada
Spanish: Barba Cabruna, Barba De Cabra, Barbón, Salsifí Blanco, Salsifí Común
Swedish: Äkta Haverrot, Haverrot
Tajik: Rishi Buz
Turkish: Keklikotu, Tekesakali, Pirasa Yaprakli Teke Sakali
Ukrainian: Vìvsjanij Korìn
Vietnamese: Cây Củ Hạ

Origin/Distribution

T. porrifolius is indigenous to the Mediterranean regions of southern Europe (i.e. France, Spain, Italy, Bulgaria, Greece, Romania and Yugoslavia), western Asia (i.e. western Turkey), northern Africa (i.e. northern Algeria, northern Libya, Morocco and Tunisia) and the Canary Islands. It has been introduced elsewhere into the British Isles, North America, South Africa and Australia.

Agroecology

Salsify adapts best to a moist environment on a wide variety of soils from sandy loams to clayey loams to clays. It flourishes in both disturbed and more established, productive sites. It will grow in areas with mean annual temperature of 10–30 °C and is frost intolerant.

Edible Plant Parts and Uses

Roots can be eaten raw or cooked (Grieve 1971; Hedrick 1972; Organ 1960; Facciola 1990); its flavour is mild and sweet and is said to resemble oysters (Facciola 1990). The young root can be grated in salads and eaten raw (Loewenfeld et al. 1980); older roots are best consumed cooked (Facciola 1990). Young shoots are edible raw or cooked (Hedrick 1972; Loewenfeld et al. 1980; Organ 1960; Facciola 1990). Flowers are edible raw and added to salads, and sprouted seeds can be added to salads or sandwiches (Facciola 1990). The root latex is used as a chewing gum (Yanovsky 1936; Tanaka 1976; Facciola 1990). The greens may also be eaten and have a sweet taste (Fritz et al. 1992). Salsify roots are used in soups and salads and as a coffee substitute or a dietetic medicine (Körber-Growhnee (1987) cited in Fritz et al. (1992)). Salsify is used in soups and stews; it can be boiled, cut into small pieces and creamed like asparagus. Also it can be cut into long strips, boiled and then fried in butter or mashed (Stephens 2009).

Botany

A robust, erect, biennial herb 50–110 cm high with a long cylindrical fleshy, tapering taproot (15–30 cm long and 2.5–3 cm wide, brownish yellow outside skin and white flesh) (Plate 1); older roots posses a milk sap and sparsely distally branched, glabrescent stem. Leaves are basal and cauline, alternate, sessile, sheathing lamina linear to linear lanceolate (grasslike), 20–40 cm long, entire margin, flat, straight apices, glabrescent on both surfaces and green. Flowering head is liguliflorous, solitary, terminal on long, bractless peduncle and distally inflated. Involucre is cylindrical, urn shaped or conic in bud, campanulate in flower; phyllaries are 5–11, in one series, linear to lanceolate, acute, receptacle flat to convex, glabrous and epaleate. Florets are 30–50; ligules are purple (Plate 2). Fruit is pale brown cypsela 2.5–4 cm, fusiform and ribbed with pale brown pappus.

Plate 1 Tapering fleshy cylindrical taproot (CG Kinsley)

Plate 2 Purple flowering head (M. Charters)

Nutritive/Medicinal Properties

The proximate nutrient composition of salsify root per 100 g edible portion had been reported as water 77 g, energy 82 kcal (343 kJ), protein 3.30 g, total lipid 0.2 g, ash 0.9 g, carbohydrate 18.60 g, total dietary fibre 3.3 g, Ca 60 mg, Fe 0.70 mg, Mg 23 mg, P 75 mg, K 380 mg, Na 20 mg, Zn 0.38 mg, Cu 0.089 mg, Mn 0.268 mg, Se 0.8ug, vitamin C 8 mg, thiamine 0.08 mg, riboflavin 0.220 mg, niacin 0.5 mg, pantothenic acid 0.371 mg, vitamin B6 0.277 mg and total folate 26ug (USDA, ARS 2014). The volatile fraction of salsify aerial parts comprised mainly of carbonylic compounds (24.6 %), phenols (21.5 %) and fatty acids and esters (19.7 %) (Formisano et al. 2010). The most abundant compounds were 4-vinyl guaiacol (19.0 %), hexadecanoic acid (17.9 %), hexahydrofarnesyl acetone (15.8 %) and hentriacontane (10.7 %). More than 80 of the volatile compounds mainly high molecular weight sesquiterpenes, acids and esters were identified in salsify (Riu-Aumatell et al. 2011). They found that headspace solid-phase microextraction (HS-SPME) was useful for the analysis of alcohols and hydrocarbons of low molecular weight and high volatility that are involved in the characteristic volatile profile of salsify and its sensory perception. The average content of inulin in fresh salsify roots was 15.17 % (Konopiński 2009). Total sugar content of salsify root was found to be 33.6 %; the low DP (degree of polymerization) compounds (oligosaccharides with DP2 to DP7) formed the majority representing 86.6 % of total sugars (Beirão-da-Costa et al. 2009). Sucrose was the main sugar (25.4 %) corresponding to 75.6 % of total sugars, glucose 2.3 %, fructose 2.2 %, oligosaccharides with DP3 3.2 % and oligosaccharides with DP7 0.5 %. Salsify root had a low calorific value but rich in proteins, vitamin B6, fibre, Ca, Fe, Mg, K, riboflavin and 4–11 % fructans (inulin and/or frutooligosaccharides).

The flavonoids, isoorientin, isovitexin, lucenin-1, luteolin, orientin, quercetin 3-*O*-β-D-gluoside, vicenin-1, vicenin-2 and vitexin, were detected in *T. porrifolius* (Kroschewsky et al. 1969). Rees and Harborne (1984) reported quercetin in all five of the *Tragopogon* species examined: *T. crocifolius*, *T. hybridus*, *T. longirostris*, *T. porrifolius* and *T. pratensis*.

T. porrifolius afforded a number of acylated pentacyclic triterpene saponins, tragopogonsaponins

A–R (Warashina et al. 1991). The ubiquitous quinic acid derivatives chlorogenic acid and 3,5-dicaffeoylquinic acid were identified by HPLC/DAD and HPLC/MS in crude extracts of subaerial parts of *T. porrifolius* (Zidorn et al. 2003). Apigenin (4′,5,7-trihydroxyflavone), apigenin 8-C-β-D-glucopyranoside (vitexin), luteolin (3′,4′,5,7-tetrahydroxyflavone), luteolin 8-C-β-D-glucopyranoside (orientin), apigenin 6-C-α-L-arabinopyranosyl-8-C-β-D-glucopyranoside (isoschaftoside) were identified from salsify (Sareedenchai et al. 2009). Three accessions of *Tragopogon porrifolius* subsp. *porrifolius* yielded three new bibenzyl derivatives 5,4′-dihydroxy-3-α-l-rhamnopyranosyl-(1→3)-β-D-xylopyranosyloxybibenzyl, 2-carboxyl-3,4′-dihydroxy-5-β-D-xylopyranosyloxybibenzyl and tragopogonic acid (2′carboxyl-3′,5′,4″-trihydroxyphenylethanone), and scorzocreticoside 1 and 6-*O*-methylscorzocreticoside I (Zidorn et al. 2005), and yielded (7*S*,15*S*)-2,4,12-trihydroxy-7-(4-hydroxyphenyl)-10-methoxy-15-(4-methoxyphenyl)-7,8,15,16-tetrahydrodibenzo[*c*,*i*][1,7] dioxacyclododecine-5,13-dione, named tragoponol, a dimeric dihydroisocoumarin (Zidorn et al. 2010). Tragoponol was made up of open-chained forms of two different monomethoxylated dihydroisocoumarin moieties, scorzocreticin and hongkongenin, which were connected via two ester bonds to form a macrolide with two lactone moieties featuring a 12-membered ring. From *Tragopogon porrifolius*, 2,4-dihydroxy-6-[2-(4-hydroxyphenyl)-2-oxoethyl]-benzoic acid was isolated; this compound was deemed to be a biogenetic intermediate between dihydrostilbenes and dihydroisocoumarins (Zidorn 2007). β-amyrin was isolated from the aerial parts (Hariri et al. 2013).

Antioxidant Activity

Two bibenzyls showed moderate, and two dihydroisocoumarins showed weak 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activities (Zidorn et al. 2005). The methanolic extract of the aerial part of *T. porrifolius* exhibited antioxidant activity of 744 μmol Fe^{2+}/g in the FRAP assay (Mroueh et al. 2011). The extract was found to contain 37.1 mg/g GAE total phenolic content and 16.6 mg/g QE flavonoid content per gram dry weight of the extract.

Antihyperlipidaemic Activity

Studies showed that consumption of salsify aerial parts extract for a period of 4 weeks resulted in a marked improvement of the lipid profile (triglycerides, total cholesterol, LDL and HDL cholesterol) in rats fed a high-carbohydrate or high-fat diet (Zeeni et al. 2013). Body weight, food intake and intra-abdominal fat were also lower in animals given salsify extract (100 and 250 mg/kg). Additionally, *T. porrifolius* extract preload produced a dose-dependent decrease in food intake observed over 24 hours. The intake of *T. porrifolius* aqueous extract therefore improved lipidaemia and increased satiety in rats with no visible adverse effects.

Hepatoprotective Activity

The methanolic extract of the aerial part of *T. porrifolius* exhibited protective effect against CCL_4-induced hepatotoxicity in rats (Mroueh et al. 2011). In-vivo, the extract (50, 100 and 250 mg/kg body weight) exhibited a dose-dependent increase in the activity of liver antioxidant enzymes. The highest dose used increased the activity of catalase, superoxide dismutase and glutathione S-transferase by 222, 149 and 68 %, respectively. *T. porrifolius* extract also showed substantial hepatoprotective capacity against CCL4-induced hepatic injury by restoring the activity of aspartate aminotransferase, alanine aminotransferase and lactate dehydrogenase to normal levels at 250 mg/kg body weight dose.

Anti-inflammatory Activity

The methanolic extract of salsify aerial parts exhibited maximum anti-inflammatory activity (60 %, 250 mg/kg), followed by ethyl acetate

(36 %, 250 mg/kg) and chloroform (29 %, 100 mg/kg) extract, when compared with the untreated control group when tested using the carrageenan-induced paw oedema model in mice (Hariri et al. 2013). The inhibition of paw oedema by the methanolic extract was comparable in effect to that of diclofenac (10 mg/kg) treatment (69 %). GC-MS analysis revealed the presence of β-amyrin acetate in the three extracts: 20.9 % in the methanolic (major), 9.52 % in the ethyl acetate and 7.42 % in the chloroform extracts. β-amyrin acetate had been reported in the literature to possess anti-inflammatory and nociceptive activities and might be partly responsible for the anti-inflammatory effects of the three *Tragopogon porrifolius* extracts.

Antifatigue/Antianoxia Activities

Administration of *Tragopogon porrifolius* root extract was found to have an antifatigue effect in mice by prolonging the duration of swimming and stick climbing (Long and Tian 1990). The extract also enhanced the tolerance of anoxia in several models of rats and mice.

Traditional Medicinal Uses

Salsify is used in herbal medicine as a cleansing food and is perceived to have a beneficial effect upon the liver and gall bladder (Chevallier 1996). The root is antibilious, slightly aperient, deobstruent and diuretic (Grieve 1971; Lust 1974). It is especially employed in the treatment of obstructions of the gall bladder and jaundice (Chopra et al. 1986) and is also used in the treatment of arteriosclerosis and high blood pressure (Chevallier 1996).

Other Uses

Besides being used as food vegetable, salsify also has medicinal uses and is cultivated in home gardens for both purposes.

Comments

Salsify (*Tragopogon porrifolius*) is regarded as an environmental weed in Victoria, South Australia, Tasmania, Western Australia and the ACT.

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Ullucus tuberosus

Scientific Name

***Ullucus tuberosus* Caldas**

Synonyms

Basella tuberosa Kunth, *Chenopodium tuberosum* Ruiz, *Gandola tuberosa* Moq., *Melloca peruviana* Moq., *Melloca tuberosa* (Kunth) Lindl., *Ullucus aborigineus* Brücher, *Ullucus kunthii* Moq., *Ullucus tuberosus* subsp. *aborigineus* (Brücher) Sperling, *Ullucus tuberosus* f. *albiflorus* Kuntze, *Ullucus tuberosus* f. *rubriflorus* Kuntze

Family

Basellaceae

Common/English Names

Ulluco, Melloco, Tuberous Basella

Vernacular Names

Argentina: Olloco, Tuna Ullush, Ulluca, Ulluma (Spanish)
Bolivia: Papa Lisas, Lisas, Olluco, Ulluco (Spanish)
Columbia: Chugua (Chibchan), Lao (Paez), Camarones De Tierra, Chigua, Chuguas, Melloco, Olluco, Rubas, Hubas, Ruhuas, Ulluco (Spanish)
Ecuador: Ulluma (Aymara), Melloco, Oca Quinq, Olluco, Rubas, Ulluco (Spanish)
French: Baselle Tubéreuse, Baselle Tubéreuse Cultivée
Peru: Chcucchanlisas, Ollucu, Ulluco, Ullucu, Ulluku (Quechuan), Lisas, Papalisa, Papa Lisas (Spanish)
Swedish: Ulluko
Venezuela: Michuri, Michiruí Migurí, Mucuchi, Ruba, Rubia, Timbós, Tiquiño

Origin/Distribution

Ulluco is indigenous to the Andean mountains and is completely a domesticated crop in Peru, Bolivia, Columbia, Ecuador and northern Argentina. Wild forms are found in Peru, Bolivia and northern Argentina. The area of cultivation extends from northern Argentina (23°S) to Columbia (9°N). It has been introduced to New Zealand, Australia, Sri Lanka and elsewhere.

Agroecology

In its native Andean range, ulluco is found at mid (2,500 m) to high altitudes 4,250 m (Parra-Quijano et al. 2012). It adapts well to temperate

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areas and will grow in the cooler and moist tropical highlands. Ulluco is frost resistant and thrives well in moist conditions and is moderately drought tolerant. Although ulluco's water requirements are unknown, it has been reported to be probably in the range of 800–1,400 mm per year during the growing season in the Andes.

Although they thrive under high light intensities, ulluco plants produce tubers poorly in hot climates. Ulluco was found to be characterised by absolute requirement for long day length for flowering and short day length for tuberisation (Markarov 2002). Day lengths of 10–13.5 hours are normally needed for tuber production. They found that cold nights retarded the destruction of gibberellic acid in plants during the dark period of diurnal cycle and ensured a permanently high level of gibberellins, which facilitated flowering of long-day species under short-day conditions. The high level of abscisic acid was considered a plant response to short-day conditions, which was favourable for tuberisation.

Ulluco tolerates a wide range of soil conditions but thrives best in a fertile, well-drained loamy soils, rich in organic matter, with a pH between 5.5 and 6.5.

Edible Plant Parts and Uses

Of the three Andean tubers (oca, maca and ulluco), ulluco is the most popular and commonly served on tables in rural and urban homes in the Andean region. Its tubers have been eaten by millions of people since the ancient times. The major appeal of the ulluco is its crisp texture which remains when cooked, like the jicama. Traditional ulluco food preparations include *mellocos* soup in Ecuador, *olluquito con charqui* (ulluco with meat) in Peru, *chupe* (potato, meat, egg, cheese stew) and *aji de paplisas* (ulluco pepper) in Peru and Bolivia (Arbizu and Tapia 1994). Ulluco tubers are also pickled or mixed with hot sauces. Generally, however, they are used to thicken soups and stews. For this, they are preferred to potatoes, because they yield a smooth, silky soup rather than a grainy one. In urban households and restaurants in Ecuador, they are frequently boiled and served cold as salad. In Columbia, ulluco is used as a basic ingredient together with cubio (*Tropaeolum tuberosum*) in the typical Colombian dish *cocido boyacense*. Tubers are also frozen and dried alternately and stored to produce a long-lasting product called *lingli* in Peru. Such processed tubers have a much stronger taste than the fresh ones. They are usually ground into flour and added to cooked foods. The green leaves of ulluco are also nutritious. In Colombia and Peru, the mucilaginous ulluco leaves are occasionally eaten in salads and as a vegetable (Parra-Quijano et al. 2012). They are also sometimes boiled to make soup or used like Malabar spinach, which they resemble in taste. Ulluco is grown and marketed as earth gems in New Zealand.

Botany

An erect, compact, low growing 20–50 cm or trailing prostrate succulent, mucilaginous annual herb, producing new shoots from tubers. Stem angular with decurrent ridges, greenish or reddish. Stolons bearing tubers. Tubers vary in shape, size and colour; shapes vary from subspherical, oblongish, rhomboid to elongate, cylindrical and falcate, thin skinned and with waxy, glossy surfaces of various colours ranging from white, light green, yellow, pink, orange, magenta, red or magenta spots mixed on a yellow background (Plate 1). Leaves alternate, glabrous, simple cordate (heart-shaped) margins smooth,

Plate 1 Ulluco tubers © International Potato Center (CIP)

entire, on long petioles. Inflorescence an axillary raceme. Flowers pedicellate, subtended by a pair of hornlike bracteoles free to base, persistent; sepals two yellowish, petals five yellowish to reddish, connate at base and adnate to petals, inserted on a shallow floral cup. Stamens 5 epipetalous, with erect filaments connate and adnate for half their length to petals, anther basifixed, deltoid thecae connate at apex, dehiscence of anthers by pore-like slits. Nectary annular. Ovary superior, 3 carpellate, unilocular with one basal ovule. Style single; stigma simple and mammilose. The fruit is an obovate, dry indehiscent nutlet, rugose, partially enclosed in parchment-like perianth, containing one seed with thin rust-coloured testa inside the thickened fruit wall. The embryo is strongly curved and encircles the scanty perisperm.

Nutritive/Medicinal Properties

Ulluco contained high carbohydrate and fibre levels, moderate protein and low fat (Busch et al. 2000). Their sensory evaluation study found that red was the most preferred skin and tissue colour of ulluco over plain yellow and mixtures of yellow, green and red. There were no significant differences in panellists' preferences for taste between ulluco cultivars, although panellists disliked the appearance of the multicoloured cultivars.

The nutritional composition (dry weight basis) of ulluco tubers was reported as protein 10.8–15.7 %, carbohydrate 73.5–81.1 %, fat 0.1–1.4 %, ash 2.8–4.2 %, fibre 3.6–5.0 %, moisture 86.0–86.2 % and energy 370–381 cal/100 g (King and Gershoff 1987). They also contained all of the essential amino acids (mg/g protein): lysine 41–55 mg, threonine 23–30 mg, valine 33–37 mg, isoleucine 34–48 mg, leucine 41–57 mg, phenylalanine + tyrosine 49–70 mg, tryptophan 7.6–10.6 mg and methionine + cystine 27–34 mg.

Nutrient values (ppm, dry weight basis) of ulluco tubers were also reported by Duke (1994) as carbohydrate 118–912 ppm, protein 10–73, fat 2–14.6, fibre 3–44, ascorbic acid 230–1,750, Ca 30–365, Fe 7–58, P 340–2,775, riboflavin 0.2–2.2, thiamine 0.4–4.3, β-carotene 0.7 and energy 500–3,725 Kcal.

From *Ullucus tuberosus* were isolated: three flavonoids, rutin, narcissin and kaempferol 3-*O*-(2″,6″-di-*O*-α-L-rhamnopyranosyl)-β-D-glucopyranoside (Dini et al. 1991a); two triterpenoid saponins were isolated 28-*O*-β-D-glucopyranosyl-epihederagenine and 28-*O*-β-D-glucopyranoside-3-*O*-β-D-glucopyranosyl (1″→2′)-β-D-glucopyranosyl-oleanoate (Dini et al. 1991b). Three triterpenoid saponins, tuberosides A, B and C were isolated as sodium and choline salts from the methanolic extract of the tubers of *Ullucus tuberosus* (Espada et al. 1996).

Both the yellow and red ulluco tubers were rich in yellow betaxanthins, and the most prominent among the 20 identified were histidine-betaxanthin, arginine-betaxanthin and glutamine-betaxanthin (Svenson et al. 2008). Twelve betacyanins were found in red tubers, with roughly 50 % of this content being betanin/isobetanin. Betacyanin levels vary from 41.2 up to 70.4 μg/g fresh weight in red tubers but were below quantifiable levels in yellow tubers. Betaxanthin levels were up to 50 μg/g fresh weight in yellow tubers. Low concentrations of betalains were detected in leaves, whereas stems contained total levels similar to the tubers, with dopamine-betaxanthin and betanin being the major pigments.

Ulluco tuber was reported to contain up to 85 % moisture, 1–2 % protein and 14 % carbohydrate. According to Gross et al. (1989), the main sugars were glucose and fructose. Chemical composition of ulluco tubers was reported as follows: protein 8.06 %, lipid 0.65 %, soluble fibre 6.49 %, insoluble fibre 7.22 %, total sugar 5.26, starch 64.96 %, mineral residues 5.40 % and moisture 87.40 % (Valcárcel-Yamani et al. 2013). Chemical composition of ulluco starch was reported as lipid 0.08 %, starch 99.05 %, amylose 26.49 %, mineral residues 0.17 % and moisture 10.97 %. Ulluco starch granules consisted of ellipsoid, oval, conical, pear-shaped and prismatic forms, ellipsoids and oval granules with lengths up to 32.09 μm. Ulluco starch had less swelling power, forming opaque, less firm gels.

The physical, chemical and functional characterisation of starches from Andean tubers oca, mashua and ulluco suggested that these starches could be used in food systems and other industrial applications, in products that require easy cooking, high viscosity and stability under refrigeration and that do not need to be frozen. The absence of protein in the isolated starches indicated the utility of these starches for preparing syrups with high glucose content. The starches were found to cook easily and to have a high degree of swelling and solubility, high viscosity, low stability to stirring and cooking or mechanical action and a low tendency towards retrogradation. These starches showed high clarity but with high syneresis when subjected to freeze–thaw cycle.

The seeds of ulluco were formed sexually and not apomictically and contained the following enzyme systems: malate dehydrogenase, glutamate oxaloacetate transaminase and 6-fosfoglucose dehydrogenase (Pietila et al. 1990).

Antioxidant Activity

For ulluco tubers, the hydrophilic antioxidant capacity (HAC) as determined by ABTS (2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)) ranged from 483 to 1,524 μg TE/g, and when expressed on a phenolic basis, the highest specific HAC among the ulluco genotypes was found in genotype DP-03-43 with 2,322 mg TE/g chlorogenic acid equivalent (Campos et al. 2006). Ulluco did not present any lipophilic antioxidant capacity for the genotypes studied. Ulluco tubers had the lowest total phenolic content which ranged from 0.41 to 0.77 mg/g and had no anthocyanins and carotenoids. Ulluco tuber pigments corresponded to betalains in the base form of betacyanins (red pigment TBS) and acid form of betaxanthins (yellow pigment TBX). TBX in ulluco tubers ranged from 22 to 96 μg/g; only one genotype with red tubers presented betacyanins TBS = 64 μg/g. A low correlation between HAC and total phenolic content was observed ($R^2 = 0.64$), most likely due to different phenolic profiles among ulluco cultivars. Among the phenolics present in ulluco, the flavonoid kaempferol had been reported to exhibit strong antioxidant activity. HAC and TBX were not correlated, suggesting that the TBX does not contribute to the HAC in ulluco. According to the results obtained, the HAC range values for the crops studied followed the descending order mashua ≥ oca ≥ native potato ≥ ulluco.

Hypoglycaemic Activity

Three triterpenoid saponins, tuberosides A, B and C isolated from ulluco tubers, showed hypoglycaemic activity (Espada et al. 1996).

Other Uses

The plant is primarily grown as a root vegetable and secondarily as a leaf vegetable; no other uses have been recorded.

Comments

The crop is normally propagated by planting small tubers. The tubers sprout and grow readily when temperatures rise above about 18 °C. However, the plant is also easily propagated by stem cuttings.

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Armoracia rusticana

Scientific Name

***Armoracia rusticana* P. Gaertn., B. Mey. & Scherb**

Synonyms

Armoracia armoracia Cockerell ex Daniels, *Armoracia lapathifolia* Gilib. (inval.), *Armoracia rustica* Schur, *Armoracia sativa* Bernh., *Cardamine armoracia* (L.) Kuntze, *Cochlearia armoracia* L., *Cochlearia lancifolia* Stokes, *Cochlearia lapathifolia* Gilib. (inval.), *Cochlearia rusticana* Lam. (illeg.), *Cochlearia variifolia* Salisb., *Crucifera armoracia* E.H.L. Krause, *Nasturtium armoracia* (L.) Fr., *Raphanis magna* Moench, *Raphanus rusticanus* Garsault (inval.), *Rorippa armoracia* (L.) Hitchc., *Rorippa rusticana* (P. Gaertn., B. Mey. & Scherb.) Godr.

Family

Brassicaceae

Common/English Names

Creole Mustard, German Mustard, Horseradish, Horse-Reddish Root (Archaic), Pepper Root, Pepper Turnip, Red Cole, Red Horseradish

Vernacular Names

Afrikaans: Peperwortel
Albanian: Rrapane, Rrikë
Amharic: Fejelee
Arabic: Feegel, Fjal Haar
Armenian: Bogkwairi, Khreni, Xreni
Azeri: Adi Xardal
Basque: Bitxaleka
Belarusian: Kapustny, Khren, Keyzakvety Chrjan
Brazil: Raiz-Forte, Razi Forte
Breton: Gouez-Irvin, Roforz
Bulgarian: Chrjan, Khryan
Chinese: La Gen (Mandarin), Laahat Gan (Cantonese)
Croatian: Vrtni Hren
Czech: Křen Selský
Danish: Almindelig Peberrod, Peberrod
Dutch: Boereradijs, Kreno, Meredik, Mierik, Mierikswortel
Eastonian: Aed-Mädarõigas, Mädarõigas, Mädarõikaseemned
Esperanto: Armoracio, Kreno
Farsi: Torob
Finnish: Piparjuuri, Pippurijuuri
French: Cran, Cranson, Mérédic, Cran De Bretagne, Grand Raifort, Moutard Des Capucins, Moutarde Des Allemands, Moutardelle, Raifort, Raifort Cran, Raifort Sauvage
Gaelic: Càl-Nan-Each, Meacan-Each, Meacan Ragaim

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German: Bauernsenf, Gewöhnlicher Meerrettich, Kren, Meerradi, Meerrettich
Georgian: Khokhnat'a, Khokhnata, P'irshushkha, Pirshushkha, Pirshushxa, Xoxnata
Greek: Armorakia, Chreno, Kochliaris E Armorakia
Hausa: Zogala
Hebrew: Hazeeret Hagina, Hazeret
Hungarian: Közönséges Torma, Torma
Icelandic: Piparrót
India: Bon Mula (Assamese), Mujo Bij (Bengali), Sahjana Ki Jar, Sahijan (Hindi)
Irish: Raidis Fhiáin
Italian: Barba Forte, Cren, Crenno, Rafano
Japanese: Hoosu Radiishu, Seiyou Wasabi, Uma-Daikon, Wasabi-Daikon
Kazakh: Aqjelkek, Chren, Jelkök, Tübirtamır
Kirgiz: Chren
Korean: Gyeo-Jamu, Holsuraediswi, Hosuraediswi, Hosurediswi, Kyo-Jamu
Latvian: Mārrutki
Lithuanian: Krienas, Valgomasis Krienas
Luxembourgeois: Paerdsrennen
Macedonian: Ren, Morsko Orevče
Mongolian: Tunhuu
Norwegian: Peparrot, Pepperrot
Ossetian: Tutturghan, Tutturqan
Philippines: Kamunggay (Cebuano), Malunggay (Tagalog)
Polish: Chrzan, Chrzan Pospolity
Portuguese: Armorácia, Mostarda Dos Monges, Rabanete De Cavalo, Rábano Picante, Rábano Picanto, Rábano Rústico, Rábano Silvestre, Raiz Forte
Provençal: Arrifouar, Rifouart
Romanian: Hrean
Russian: Khren, Khren Obyknovennyi
Serbian: Hren, Ren
Slovašcina: Hren Navadni, Navadni Hren
Slovencina: Chren Dedinský
Spanish: Jaramago Oficinal, Rábano Picante, Rábano Rusticano, Taramago
Swahili: Mronge
Swedish: Pepparrot
Thai: Hosraedit
Turkish: At Turpu, Bayır Turpu, Hindiba, Karaturp, Yaban Turbu
Turkmen: Adaty Hren
Ukrainian: Chrin, Khrin Zvychajnyj
Uzbek: Khartoi, Yerqalampir
Vietnamese: Cây Rau Họ, Cây Cải Ngựa, Hren, Ren
Vlaams: Mierikswortel
Welsh: Rhuddygyl Mawrth, Rhuddygl Y Meirch, Rhyddygl Poeth
Yiddish: Khrayn, Khreyn

Origin/Distribution

Its exact origin is obscure, most probably Eastern Europe (S. Russia, Ukraine) and west Asia. However, no natural populations of *Armoracia rusticana* were found in Austria, Bulgaria, Romania or Russia (Sampliner and Miller 2009). Horseradish is now cultivated widely in Europe and North America, where it has frequently naturalised.

Agroecology

A cool climate species, it grows in temperate and subtemperate areas with temperature range of 5–19 °C and annual rainfall of 500–1,700 mm. It is found growing in yards, gardens, roadsides, ditches, banks, waste ground, rubbish tips and waterside meadows. Although the plant will grow on any soil type, the best growth is found in deep, well-drained, moist, fertile, loamy soil high in organic matter with soil pH of 5–7.5 (6.8). It grows in full sun to partial shade.

Edible Plant Parts and Uses

Horseradish roots and leaves are eaten especially in Europe. Horseradish has very pungent roots that are used as condiment and contain oil with a strong pungent odour and hot, biting taste. As a condiment the horseradish root is usually grated or minced and mixed with vinegar, salt, cream, oil, tomato or yogurt or other flavourings to make sauce, paste or relish in Bulgaria, Romania and Russia (Sampliner and Miller 2009). These are often used with fish or other seafood or as an

appetiser with meats. Grated horseradish is also employed as an ingredient in some catsups and mustards and, in salads, as a condiment for any cooked meat (e.g. lamb, pig and chicken) and mixed with red beets or other vegetables as garnish. In Romania, grated roots, with or without oil, are eaten with potatoes or polenta or are grilled and eaten with cream accompanying lamb and chicken; a mix of grated horseradish, apples, salt, sugar and vinegar is used as garnish for meals, while small pieces of the root are eaten in soups. In Tomsk (Russia), *A. rusticana* or *A. sisymbrioides* roots are grated and mixed with tomato and other spices to make a sauce. In Austria, freshly grated horseradish (or tinned product) is frequently mixed with grated apples (sour varieties preferred), and this mixture called *Apfelkren* is then eaten as a spicy relish to fried or cooked meat. In Bulgaria, Romania and Russia, the whole root, grated root or root pieces are still used to flavour, help ferment, aerate pickling liquid and conserve cabbage for the winter. In Germany, horseradish roots cut in very small pieces, crushed and mixed with salt and vinegar are often added to fish and meat dishes and also mixed in catsup used to flavour ground beets or added to mustard as a seasoning (Courter and Rhodes 1969). In Poland, roots and leaves are used for seasoning or as preservatives: the roots are utilised as a condiment, with pickled cucumbers, grated with chopped boiled eggs, soups or meat dishes, often used at Easter (Łuczaj Szymański 2007). Horseradish was used by European Jews as a symbolic food in the ritual meal as bitter herb of Passover because its bitterness reflected the suffering of their ancestors of the Exodus from Egypt (Schaffer 1981).

Horseradish root is still relished in Europe and North America and is appreciated freshly grated, mixed with vinegar or in a sauce to form a condiment often used with meats or fish and as a flavour in other recipes in salads and soups, on sandwiches and in cocktail drinks such as the Bloody Mary (Wedelsback Bladh and Olsson 2011).

In Bulgaria, Romania and Russia, *Armoracia rusticana* roots and leaves are used in the pickling of various vegetables including cucumbers, carrots, peppers or mixed vegetables (Sampliner and Miller 2009). In Romania, horseradish leaves are used for *sarmale*, a Romanian dish made from meat, rice and vegetables wrapped in *A. rusticana* leaves and then boiled; the leaves can also be put into bread dough, which is then grilled. Leaves can also be cut and used to conserve cut vegetables for the winter. The leaves of *A. rusticana* are used as an antiseptic or clearing ingredient as well as a fermenting agent in the preparation of alcohols in Bulgaria and Romania. They are used in the preparation of *tuica* (a Romanian fruit brandy). In Russia, leaves of *A. rusticana* and *A. sisymbrioides* are used for preparing canned cucumbers and conserves (Sampliner and Miller 2009). In Italy, the leaves are used for salad and mixed with other vegetable species (Pieroni et al. 2005; Sarli et al. 2012). In Poland, the leaves are placed in the oven under baking bread, partly to prevent the bread from sticking and partly to flavour the bread (Łuczaj and Szymański 2007). Horseradish is also often consumed boiled as a pot herb (Shehata et al. 2009).

Botany

An erect, glabrous robust, herbaceous, rhizomatous perennial, 50–120 cm high (Plate 1), branching sparsely in the upper part with a fleshy, pungently aromatic, fusiform or cylindrical taproot (Plate 2). Basal leaves few, alternate and in a rosette, long petiolate, 10–30 cm long, with elliptic–ovate or oblong–lanceolate, bluish green, lamina with cordate base and crenate, undulating margins (Plate 1). Proximal cauline leaves entire to pinnately lobed and serrate, distal cauline leaves alternate, sessile to subsessile, smaller than lower leaves, lanceolate, crenate, serrate or entire. Flowers in a terminal raceme, mildly fragrant, actinomorphic, small, 1–.5 cm wide, sepals 4 ovate; petals 4 white, 5–8 mm long, obovate and rounded; stamens 6, 4 long and 2 short, style 5 mm with capitates stigma, ovary with 8–12 ovules in two rows per chamber. Fruit a silique, 4–6 mm long, rarely produced, ovoid to obovate, few-seeded, generally aborted or weakly developed.

Plate 1 Horseradish plant

Plate 2 Horseradish roots

Nutritive/Medicinal Properties

Root Nutrients/Phytochemicals

The proximate nutrient composition of horseradish (prepared) per 100 g edible portion had been reported as water 85.08 g, energy 48 kcal (201 kJ), protein 1.18 g, total lipid 0.69 g, ash 1.76 g, carbohydrate 11.29 g, dietary fibre 3.3 g, total sugars 7.99 g, Ca 56 mg, Fe 0.42 mg, Mg 27 mg, P 31 mg, K 246 mg, Na 420 mg, Cu 0.05 mg, Mn 0.126 mg, Se 2.8 μg, vitamin C 24.9 mg, thiamine 0.08 mg, riboflavin 0.024 mg, niacin 0.386 mg, pantothenic acid 0.093 mg, vitamin B6 0.073 mg, total folate 57 μg, total choline 6.5 mg, β-carotene 1 μg, vitamin A 2 IU, lutein + zeaxanthin 10 μg, vitamin E (α-tocopherol) 0.01 mg, vitamin K (phylloquinone) 1.3 μg, total saturated fatty acids 0.09 g, 12:0 (lauric acid) 0.002 g, 14:0 (myristic acid) 0.001 g, 16:0 (palmitic acid) 0.061 g, 18:0 (stearic acid) 0.021 g, total monounsaturated fatty acids 0.130 g, 16:1 undifferentiated (palmitoleic acid) 0.001 g, 18:1 undifferentiated (oleic acid) 0.127 g, 20:1 (gadoleic acid) 0.001 g, 22:1 undifferentiated (erucic acid) 0.001 g, total polyunsaturated fatty acids 0.339 g, 18:2 undifferentiated (linoleic acid) 0.285 g,18:3 undifferentiated (linolenic acid) 0.053 g and phytosterols 9 mg (USDA-ARS 2014).

Volatile organic compounds found in fresh and 12 hours horseradish samples (ppm) were determined by D'Auria et al. (2004), respectively, as thiobismethane (0.8, 1.4 ppm) carbon disulfide (0.8,0 ppm), 3-butenenitrile (2.38, 0 ppm), 3-methylbutanal (0.4,0.6 ppm), 2-ethylfuran (1.2,5.8 ppm), hexanal (4.5, 3 ppm), *E*-2-hexenal (1.6, 3 ppm), allyl isothiocyanate (3,300,175 ppm), isobutyl isothiocyanate (15,0 ppm), 4-isothiocyanato-1-butene (63,0 ppm), butyl isothiocyanate (13,0 ppm), butyl isothiocyanate (13,0 ppm), 3-methylbutyl isothiocyanate (8.6,0 ppm), pentyl isothiocyanate (3.7,0 ppm), nonanal (1.6,1.4 ppm), 4-methylpentyl isothiocyanate (0.4,0 ppm), benzenepropanenitrile

(0.8, 0.2 ppm), benzyl isothiocyanate (14,8.8 ppm), 2-phenylethyl isothiocyanate (400, 432 ppm), 3-methyl-1-butanol (0,1.4 ppm), toluene (0,0.8), heptanal (0,0.3 ppm), benzaldehyde (0,0.5 ppm), 2-pentylfuran (0, 3 ppm), 2-ethyl-1-hexanol (0,1.8 ppm), phenylacetaldehyde (0, 0.3 ppm), 4-ethylbenzaldehyde (0,0.4 ppm), l-(−)-menthol (0, 0.2 ppm), naphthalene (0, 0.2 ppm), decanal (0, 0.5 ppm), *trans*,*trans*-nona-2,4-dienal (0, 0.2 ppm), junipene (0,0.2 ppm) and italicene (0,0.8 ppm). Several new compounds were detected 12 hours after fresh horseradish was cut. Thiobismethane was also identified as a flavour component. The presence of four aldehydes, viz. 3-methylbutnal, hexanal, E-2-hexanal and nonanal, probably contributed to its aromatic bouquet.

In horseradish sprouts and roots, Agneta et al. (2012) confirmed the presence of sinigrin, 4-hydroxyglucobrassicin, glucobrassicin, gluconasturtiin and 4-methoxyglucobrassicin and identified glucoiberin, gluconapin, glucocochlearin, glucoconringianin, glucosativin, glucoibarin, 5-hydroxyglucobrassicin, glucocapparilinearisin or glucobrassicanapin, glucotropaeolin and glucoarabishirsutain, not previously characterised in horseradish. Of particular note was the presence of the putative 2-methylsulfonyl-oxo-ethyl-glucosinolate.

Phytochelatin (PC)-related peptides including isophytochelatins (Gln) (iso-PC(Gln) (γGlu-Cys) n-Gln, $n = 3–4$) were identified in horseradish hairy roots exposed for 3 days to cadmium (1 mM) along with reduced glutathione (2 mM) (Kubota et al. 2000).

A full-length cDNA encoding myrosinase (ArMY1) was cloned from horseradish root (Li et al. 2007). Myrosinase (β-thioglucoside glucohydrolase) had been reported as the only known S-glucosidase in plants, catalysing the hydrolysis of glucosinolates into compounds with diverse biological activities. Horseradish peroxidase isoenzymes were found to contain fucose, arabinose, xylose and mannose; synthesis of the peptide portion of peroxidase was completed before these monosaccharide residues were attached to the molecule (Lew and Shannon 1973). Fujiyama et al. (1988) isolated, cloned and characterised three cDNAs and two genomic DNAs corresponding to the mRNAs and genes for the horseradish peroxidase isoenzyme C. The peroxidase enzyme purified from horseradish roots, a heme-containing enzyme, was homogeneous with a molecular weight of approximately 40 kDa, a high specific activity of 772 U/mg protein and an isoelectric point of 8.8 and a Reinheitszahl value of 3.39 (Lavery et al. 2010).

Studies showed that the accumulation of glucosinolate concentration in horseradish in-vitro plants had a direct association with the sulphur concentration in the medium (Alnsour et al. 2013). Cultivation in 1.7 mmol/L sulfate resulted in the accumulation of 16.2 μmol/g DW glucosinolates, while the glucosinolate concentration increased to more than 23 μmol/g DW when 23.5 mmol/L sulfate was used in the medium. Correspondingly, the glucosinolate concentration decreased to 1.6 μmol/g DW when sulphate concentration was lowered to 0.2 mmol/L.

Isaac and Kohlstaedt (1962) reported allyl isothiocyanate and β-phenylethyl isothiocyanate as the main pungent components of horseradish grown in Japan. Volatile components identified in horseradish and black mustard included: methyl isothiocyanate, isopropyl thiocyanate, methyl thiocyanate, ethyl thiocyanate, sec-butyl thiocyanate, isobutyl thiocyanate, allyl thiocyanate and 3-butenyl thiocyanate (Kishima et al. 1970). Significant level of isopropyl isothiocyanate between horseradish and black mustard was observed.

Gilbert and Nursten (1972) identified five major essence compounds in horseradish roots: allyl thiocyanate, 4-pentenyl isothiocyanate, 2-butyl isothiocyanate, β-phenylethyl isothiocyanate and allyl thiocyanate as well as methyl isothiocyanate, ethyl isothiocyanate, isopropyl isothiocyanate and 2-phenethyl isothiocyanate. Eight major volatile components were identified from horseradish roots: isopropyl isothiocyanate, allyl isothiocyanate, 3-butenyl isothiocyanate, 4-pentyl isothiocyanate, phenyl isothiocyanate, 3-methylthiopropyl isothiocyanate, benzyl iso-

thiocyanate and β-phenylethyl isothiocyanate (Kojima et al. 1973). Of the ten steam-volatile constituents identified in horseradish, six were isothiocyanates, two were nitriles, one was allyl thiocyanate and one was carbon disulfide (Mazza 1984). The distribution and concentration of flavour components in crowns, primary and secondary roots and rootlets differed from those in tops. The primary and secondary roots and crowns accounted for the bulk of the weight of the root fraction as well as its essence content.

Grob and Matile (1980) identified 30 glucosinolates in horseradish: 2-methylthioethyl-glucosinolate (glucoviorylin), isopropyl glucosinolate (glucoputranjivin), allyl glucosinolate (sinigrin), 2-hydroxypropyl-glucosinolate (glucoarabidopsithalin), 3-methylthiopropyl glucosinolate (glucoiberverin), 3-methylsulfinylpropyl glucosinolate (glucoiberin), 3-methylsulfonylpropyl-glucosinolate (glucocheirolin), *n*-butyl glucosinolate, *sec*-butyl-glucosinolate, isobutyl glucosinolate (glucoconringianin), 3-butenyl-glucosinolate (gluconapin), 3-hydroxybutyl-glucosinolate (glucocappariflexin), 4-methylthiobutyl glucosinolate (glucoerucin), *n*-pentyl-glucosinolate (glucokohlrabiin), 3-methylbutyl-glucosinolate, 2-methylbutyl-glucosinolate, 4-pentenyl glucosinolate (glucobrassicanapin), 2-hydroxypentyl-glucosinolate (glucomoracialapathin), 3-hydroxy-4-pentenyl glucosinolate, 5-methylthiopentyl-glucosinolate(glucoberteroin),3-hydroxy-5-methylthiopentyl-glucosinolate, iso-hexyl-glucosinolate structure unknown, 5-hexenyl-glucosinolate (glucowasabiamin), 6-methylthiohexyl-glucosinolate (glucolesquerellin), iso-heptyl-glucosinolate structure unknown, benzyl glucosinolate (glucotropaeolin), 2-phenylethyl-glucosinolate (gluconasturtiin), 3-phenylpropyl-glucosinolate (glucoarmoracialapicin), 4-phenylbutyl-glucosinolate (glucoarmoracialafolicin) and methoxybenzyl glucosinolate. The common names in brackets had been recognised by Fahey et al. (2001), Bellostas et al. (2007) and Clarke (2010). The accumulation of indole glucosinolates and its common precursor L-tryptophan in the vacuole of root storage tissues was reported by Helmlinger et al. (1983). The presence and concentration of indole-3-methylglucosinolate [=glucobrassicin; 0.49 μmol/g dry weight (dw)] and its 1-methoxy derivative (0.38 μmol/g dw) were determined.

Seven isothiocyanates (ITCs) were identified and measured as flavour compounds in New Zealand-grown wasabi rhizomes and horseradish roots (Sultana et al. 2003). These were isopropyl isothiocyanate, sec-butyl isothiocyanate, allyl isothiocyanate (AITC), 3-butenyl isothiocyanate (3-BITC), 4-pentenyl isothiocyanate (4-PITC), 5-hexenyl isothiocyanate C (5-HITC) and 2-phenylethyl isothiocyanate (2-PEITC). AITC was the highest concentration isothiocyanate in both wasabi (1,937.8 mg/kg of fresh rhizome) and horseradish (1,658.1 mg/kg fresh root). AITC comprised a higher proportion of the total isothiocyanate concentration of wasabi (93.7 %) than of horseradish (87.2 %). The level of 4-PITC in wasabi was 47.97 mg/kg of rhizome (2.32 % of the total isothiocyanate concentration in wasabi), whereas in horseradish the level was only 8.99 mg/kg of the root, which was significantly lower (81 %) than for wasabi. The proportion of 4-PITC of the total isothiocyanate concentration in horseradish was also very small (0.47 %). 2-Phenylethyl ITC was only detected in horseradish (185.2 mg/kg of root) and was the second highest ITC in horseradish root, contributing 9.74 % to the total isothiocyanate content. The concentrations of 3-BITC in wasabi and horseradish were not significantly different (43.13 and 39.43 mg/kg of the sample, respectively). sec-Butyl ITC was present at 18.78 mg/ kg of wasabi rhizome but was only 2.77 mg/kg in horseradish root. The proportion of sec-butyl ITC of total isothiocyanate concentration in wasabi and horseradish was very small (0.91 % and 0.15 %, respectively). The levels of isopropyl ITC in wasabi and horseradish were 12.81 mg/kg and 3.57 mg/kg, respectively. Very small amounts of 5-HITC were found in wasabi (7.06 mg/kg of rhizome) and horseradish (2.77 mg/kg of root). The total isothiocyanate content in wasabi was 2,067.55 mg/kg of rhizome, while the level in horseradish was 1,900.7 mg/kg of roots.

Chemical composition of the pungent components of *A. rusticana* grown in China was determined by Jiang et al. (2006) as isopropyl isothiocyanate (0.1 %), allyl isothiocyanate

(78.4 %), butyl isothiocyanate (0.1 %), 3-butenyl isothiocyanate (1.5 %), 2-pentyl isothiocyanate (2.1 %), phenyl isothiocyanate (0.1 %), 3-methylthiopropyl isothiocyanate (0.3 %), benzyl isothiocyanate (0.1 %) and β-phenylethyl isothiocyanate (9.4 %). A total of 15 volatile compounds were detected in various Latvian horseradish genotype roots: 2-butyl isothiocyanate, isobutyl isothiocyanate, allyl isothiocyanate, 3-methylbutyl isothiocyanate, 3-butenyl isothiocyanate, pentyl isothiocyanate, cyclopentyl isothiocyanate, benzyl isothiocyanate, 2-phenethyl isothiocyanate and the rest unidentified (Tomsone et al. 2013). The main compound in all horseradish samples was allyl isothiocyanate constituting 64–82 % of total identified volatile compounds; the samples also contained significant amounts of 2-phenylethyl isothiocyanate (4–26 %).

The content of allyl isothiocyanate (AITC) in creamy and white horseradish roots ranged from 800 to 2,000 mg/k fresh weight (Horbowicz and Rogowska 2006). The concentration of phenylethyl isothiocyanate (PEITC) in roots of both horseradish types was 3–10 times lower than AITC. The roots of creamy-type horseradish contained higher level of PEITC than the white type. A decline of PEITC level was observed during vegetation of horseradish. Kaempferol level decreased in horseradish roots during cultivation period, and only traces of quercetin in roots of both horseradish types were detected. Freshly harvested roots of the Polish horseradish contained higher content of analysed allyl and phenylethyl isothiocyanates (AITC and PEITC) in comparison to horseradish of the Hungarian origin (Kosson and Horbowicz 2008). During long-term storage in cold room (0–1 °C), variation of content of both isothiocyanates was observed, but mean level of the pungent compounds: AITC and PEITC. During long-term storage of both horseradish root types in cold room, the significant decline of ascorbic acid content was noted, but after 10 months of storage period, its level was still high. They found that the higher the temperature of storage, the higher the content of reducing sugar in horseradish cream was observed (Kosson and Horbowicz 2009). Content of allyl isothiocyanate (AITC) and especially phenylethyl isothiocyanate (PEITC) in fresh horseradish cream was lower in comparison to non-processed horseradish roots. Content of both isothiocyanates decreased significantly during storage period. The highest decline of isothiocyanate level was observed during the first 4 months of storage. The highest temperature of storage studied (18 °C) caused faster decline of both isothiocyanate concentrations in horseradish cream.

Mevy et al. (1997) found that the qualitative production of glucosinolates was similar in both horseradish regenerated plantlets and wild plants with regard to 2-phenylethyl- and 2-propenyl-glucosinolates. In contrast, thioglucoside contents varied with cell differentiation because indole glucosinolates occurred only in calli, suspension cells and embryoids. Additionally, it was shown that the specific activity of myrosinase, the enzyme responsible for glucosinolate hydrolysis, declined with tissue age.

Horseradish plantlets produced significantly higher amounts of total glucosinolates than tumour and teratoma tissues with the aliphatic glucosinolate sinigrin being dominant (Redovniković et al. 2008). Plantlets also contained lower amounts of an aromatic glucosinolate, gluconasturtiin, and indole compounds: glucobrassicin, 4-methylglucobrassicin and 4-hydroxyglucobrassicin. In tumour and teratoma tissues, only these indole glucosinolates were detected. The activity of enzyme myrosinase (β-thioglucosidase) was significantly higher in plantlets than in teratoma tissues. No myrosinase activity was recorded in tumour tissues. Total peroxidase activity was 30–50 times higher in tumour and teratoma than in plantlets. Immobilisation of horseradish cells reduced the assimilation of the hexoses released into the culture medium (Mevy et al. 1999). Although sucrose hydrolysis occurred prior to uptake, the decrease of acid invertase activity in immobilised cells was accompanied by an increased yield (two- to threefold) of the intracellular sucrose. Glucosinolates accumulated as indolic forms only during the stationary stage of cell growth. Their amount in immobilised cells may be

increased twofold compared to the control cultures. In contrast, intracellular sucrose concentration declined, while the cleavage activity of sucrose synthase increased simultaneously with production of indole-3-methyl- and 4-hydroxy-indole-3-methyl-glucosinolates.

Total glucosinolates in accessions of horseradish roots and leaves ranged from 2 to 296 μmol/g of dry weight in both tissues (Li and Kushad 2004). Four glucosinolates (sinigrin, glucobrassicin, neoglucobrassicin and gluconasturtiin) were detected in major quantities. In fully developed roots, sinigrin concentration accounted for approximately 83 %, gluconasturtiin approximately 11 % and glucobrassicin approximately 1 % of the total glucosinolates. Approximately the same proportions of individual glucosinolates appeared in fully developed leaves, except that glucobrassicin substituted by neoglucobrassicin and gluconasturtiin concentration was significantly lower (<1 %). At least four other glucosinolates were detected in very small quantities (<1 %) in both roots and leaves. Myrosinase (β-thioglucoside glucohydrolase), the enzyme responsible for the hydrolysis of the parent glucosinolates into biologically active products, was detected in the roots and leaves, ranging from 1.2 to 57.1 units/g dw. Significant differences in myrosinase activity were detected between the roots and leaves, ranging from 1.2 to 57.1 units/g dw. In the leaves, significant correlations were found between myrosinase activity and total glucosinolates ($R^2=0.78$) and between myrosinase activity and sinigrin ($R^2=0.80$). Glucosinolate content and myrosinase activity were also correlated in young and fully developed roots and leaves and during tissue crushing. Glucobrassicin concentration in the roots and neoglucobrassicin concentration in the leaves were significantly higher in young than in fully developed tissue. Crushing of the tissue resulted in rapid hydrolysis of sinigrin and glucobrassicin, as expected, from the presence of myrosinase. Myrosinase was found to have a mass of about 130 kDa made up of two subunits of similar molecular mass of about 65 kDa, and it exhibited high activity at broad pH 5–8 and temperature (37 and 45 °C) (Li and Kushad 2005).

Horseradish root had been found to be rich in the glucosinolate sinigrin (thio-β-glucopyranosyl -1-N-sulfate-2-propenylimidate) (>80 %) followed by gluconasturtiin and glucobrassicin (Wedelsback Bladh et al. 2013). Sinigrin levels in 168 Nordic accessions varied between 10 and 45, gluconasturtiin between 1.3 and 7.4 and glucobrassicin between 0.1 and 2.6 μmol/g DM. Accessions with high levels of both sinigrin and gluconasturtiin were found. Glucosinolates and their degradation products are responsible for the characteristic pungent taste and odour of *Brassica* crops such as horseradish, cabbage, mustard and broccoli (Wedelsback Bladh et al. 2013), and myrosinase, or thioglucoside glucohydrolase, the trivial name for the enzyme, had been reported to be responsible for the hydrolysis of glucosinolates such as sinigrin into isothiocyanate following disintegration of root cells, generating the spicy taste of horseradish-containing food (Loebers et al. 2010). The products of glucosinolate hydrolysis include isothiocyanates, nitriles, thiocyanates, indoles and oxazolidinethiones (Mucete et al. 2006b). Mucete et al. (2006b) found that sinigrin–myrosinase activity can be optimised under the following conditions: temperature of 55 °C, and reaction time was of 210 minutes for rubbed out horseradish samples and of 240 minutes for unrubbed horseradish samples.

A recent review by Nguyen et al. (2013) had focused on the pharmacological properties of its major chemical compounds, allyl and phenethyl isothiocyanates, mainly in areas of anticancer and antimicrobial activities, covering in-vitro and animal studies, and pharmacokinetics.

Antioxidant Activity

Horseradish exhibited antioxidative and superoxide scavenging potency and peroxidase activity (Kinae et al. 2000). Majewska et al. (2004) found that although leaf and root extracts derived from four Polish types of horseradish did not exhibit strong antioxidant properties, the different environmental conditions of plant growth affected these properties significantly. Volatile oil obtained from horseradish roots revealed stronger

antioxidant properties than pure allyl isothiocyanate and was significantly affected by types as well as environmental factors. Diet containing horseradish had no effect on antioxidant plasma and heart activity in mice.

Horseradish extract obtained by supercritical extraction was found to have the highest antioxidant capacity, compared to fresh and lyophilised horseradish (Cirimbei et al. 2013). This was attributable to contents of flavonoid and phenols. Horseradish extract obtained by supercritical extraction had the highest contents of flavonoids rutin and quercetin and phenols gallic and tannic acids.

Antimicrobial Activity

Growth of *Staphylococcus aureus*, *Escherichia coli* O157:H7, *Salmonella typhimurium*, *Listeria monocytogenes* and *Serratia grimesii* on agar was completely inhibited for 7 days in aerobic storage at 12 °C when 4,000 nL horseradish root distillate/L air was added to a sealed model system at the outset (Ward et al. 1998). Complete inhibition of *Lactobacillus sake* required 20,000 nL/L. Bactericidal activity varied between species and increased with distillate concentration. Bacteria inoculated on roast beef were more resistant to the bacteriostatic effect of the distillate and 20,000 nL/L were required to completely inhibit growth. *Lactobacillus sake* was weakly inhibited at this concentration. Bactericidal activity was observed only for *Staphylococcus aureus*, *Escherichia coli* and *Serratia grimesii*. Differences in bacteriostatic and bactericidal activities were attributed to enhanced depletion of residual allyl isothiocyanate in the meat model system.

Isothiocyanates from cut horseradish roots were found to be inhibitory in-vitro to *Bacillus subtilis Staphylococcus aureus* and *Escherichia coli* (Mucete et al. 2006a). Horseradish extract was found to be an effective agent against saprolegniasis (Khomvilai et al. 2006). The minimum inhibitory concentration of its main constituent allyl isothiocyanate, for mycelial growth of *Saprolegnia parasitica*, was 68 mg/L after 60 minutes exposure and 42.5 mg/L for zoospore germination after 5 minutes exposure.

Isothiocyanates (ITCs) extracted from horseradish root exhibited antimicrobial activity in-vitro against oral microorganisms: six strains of facultative anaerobic bacteria, *Streptococcus mutans*, *Streptococcus sobrinus*, *Lactobacillus casei*, *Staphylococcus aureus*, *Enterococcus faecalis* and *Aggregatibacter actinomycetemcomitans*; one strain of yeast, *Candida albicans*; and three strains of anaerobic bacteria, *Fusobacterium nucleatum*, *Prevotella nigrescens* and *Clostridium perfringens* (Park et al. 2013). The minimum bactericidal concentration (MBC) of the ITCs extracted from horseradish root ranged from 1.25 to 5.00 mg/mL against six strains of facultative anaerobic bacteria and one strain of yeast and 4.17–16.67 mg/mL against three strains of anaerobic bacteria. The ITCs extracted from horseradish root showed the strongest antimicrobial activity, with an MBC of 1.25 mg/mL, against *C. albicans* among facultative microorganisms and 4.17 mg/mL against *F. nucleatum* among anaerobic bacteria.

Anticancer Activity

A combination of horseradish peroxidase and indole-3-acetic acid or its derivatives is currently being evaluated as an agent for use in targeted cancer therapies (Veitch 2004). Allyl isothiocyanate (AITC), a constituent of cruciferous vegetables including parsnip, significantly inhibited survival of PC-3 and LNCaP human prostate cancer cells in culture, whereas proliferation of a normal prostate epithelial cell line was minimally affected by AITC even at concentrations that were highly cytotoxic to the prostate cancer cells (Xiao et al. 2003). They also demonstrated that AITC administration retarded growth of human prostate cancer xenografts in-vivo (Srivastava et al. 2003). Approximately 70 % reduction in the levels of antiapoptotic protein Bcl-2 in the tumour lysate of AITC-treated mice was found compared with that of control mice. Further, the tumours from AITC-treated mice, but not control mice, exhibited cleavage of BID, known to promote

apoptosis. Statistically significant reduction in the expression of several proteins that regulated G2/M progression, including cyclin B1, cell division cycle (Cdc)25B and Cdc25C (44, 45 and 90 % reduction, respectively, compared with control), was also observed in the tumours of AITC-treated mice relative to control tumours.

Cyclooxygenase and human tumour cell growth inhibitory extracts of horseradish roots yielded active compounds plastoquinone-9 (1), 6-*O*-acyl-β-D-glucosyl-β-sitosterol (2) and 1,2-dilinolenoyl-3-galactosylglycerol (3) (Weil et al. 2005). 3-Acyl-sitosterols, sinigrin, gluconasturtiin and phosphatidylcholines isolated from horseradish were inactive. At a concentration of 60 μg/mL, compounds 1 and 2 selectively inhibited COX-1 enzyme by 28 and 32 %, respectively, while at 250 μg/mL compound 3 gave 75 % inhibition. In a dose–response study, compound 3 inhibited the proliferation of colon cancer cells (HCT-116) by 21.9, 42.9, 51.2 and 68.4 % and lung cancer cells (NCI-H460) by 30, 39, 44 and 71 % at concentrations of 7.5, 15, 30 and 60 μg/mL, respectively.

Antihypercholesterolemic Activity

Balasinska et al. (2005) demonstrated that horseradish lowered plasma cholesterol and faecal bile acid excretion in mice fed the cholesterol-enriched diet with horseradish compared with those fed cholesterol-enriched diet. Horseradish increased the excretion of cholesterol and coprostanol when compared with mice fed the control diet and with cholesterol. It was suggested that the cholesterol-lowering action of horseradish could be due to the interference with exogenous cholesterol absorption.

Antimutagenic Activity

Horseradish and wasabi (*Wasabi japonica*) exhibited antimutagenic activity towards 2-amino-3,8-dimethylimidazo[4,5-f]quinoxaline [MeIQx], a well-known mutagen/carcinogen in broiled fish and meat, and also decreased His-+ revertant colonies of 3-chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone (MX) in the Ames test, a strong mutagen and carcinogen in chlorine-disinfected tap water (Kinae et al. 2000). 3-Allyl-5-substituted 2-thiohydantoins (ATH-amino acids) derived from allyl isothiocyanate and amino acids were found to inhibit the mutagenicity of 2-amino-3-methylimidazo[4,5-f]quinoline (IQ) in the *Salmonella* assay (Takahashi et al. 2005). It was found that ATH-amino acids could act as S9 inhibitors, thereby inhibiting metabolic activation of IQ.

Insecticidal Activity (House Health Pest)

In-vitro studies showed that horseradish ethanol extracts exhibited only a fungistatic activity against *Sclerotium rolfsii*, *Fusarium oxysporum* and *F. culmorum* but showed significant insecticidal activity against larvae of the mosquito, *Aedes albopictus*, with a higher efficacy (LC_{50} value of 2.34 g/L), approximately two times higher than the garlic one (LC_{50} value of 4.48 g/L) (Tedeschi et al. 2011). Horseradish oil (24 hours LC_{50}, 1.54 μg/cm^2) and allyl isothiocyanate (2.52 μg/cm^2) were highly toxic to *Dermatophagoides farinae*, house dust mites (Yun et al. 2012). Among the other organic isothiocyanates, benzyl isothiocyanate (LC_{50}, 0.62 μg/cm^2) was the most toxic compound, followed by 4-chlorophenyl, 3-bromophenyl, 3,5-bis(trifluoromethyl)phenyl, cyclohexyl, 2-chlorophenyl, 4-bromophenyl and 2-bromophenyl isothiocyanates (0.93–1.41 μg/cm^2). All were more effective than either benzyl benzoate (LC_{50}, 4.58 μg/cm^2) or dibutyl phthalate (24.49 μg/cm^2). In the vapour-phase mortality bioassay, these isothiocyanates were consistently more toxic in closed versus open containers, indicating that their mode of delivery was, in part, a result of vapour action.

Antigenotoxic Activity

Plant extracts of *Armoracia rusticana*, *Ficus carica*, *Zea mays* and their mixture decreased the

level of mutations induced by N-methyl-N′-nitro-N-nitrosoguanidine (MNNG), an environmental mutagen, in *Vicia faba* cells, chlorophyll mutations in *Arabidopsis thaliana* and NaF-induced mutability in rat marrow cells (Agabeĭli and Kasimova 2005). *Gentiana asclepiadea* (methanolic and aqueous haulm extracts, 0.25 mg/mL) and *Armoracia rusticana* (methanolic root extract, 0.025 mg/mL) enhanced the adaptive response and decreased DNA damage (genotoxic impact) caused by zeocin in human lymphocytes (Hudecova et al. 2012).

Antioestrogenic Activity

Horseradish peroxidase (HRP) was found to oxidise known endocrine-disrupting alkylphenols such as bisphenol A (2,2-bis(4-hydroxyphenyl) propane; BPA), *p*-nonylphenol (*p*-NP) and *p*-octylphenol (*p*-OP) (Sakuyama et al. 2003). Their study showed that when Japanese rice fish (*Oryzias latipes*) were exposed to BPA, vitellogenin in the blood increased, but no increased vitellogenin was observed in medaka exposed to HRP-oxidised BPA. The enzymatic oxidation of BPA using HRP was able to eliminate its oestrogen-like activity.

Traditional Medicinal Uses

Horseradish has been used for a long time in traditional medicine for its therapeutic, stimulant, rubefacient, stomachic, diaphoretic, diuretic, expectorant, antiscorbutic, antiseptic and vermifugal properties (Grieve 1971; Cirimbei et al. 2013). Horseradish is useful in the treatments of dropsy, when infused in wine horseradish root will stimulate the whole nervous system and promote perspiration; an infusion of sliced horseradish in milk provides an excellent cosmetic for the skin (Grieve 1971). Horseradish juice mixed with white vinegar is applied externally to remove freckles, and the same mixture diluted with water and sweetened with glycerine is administered to children for whooping cough. Horseradish may help to relieve rheumatism by stimulating blood flow to inflamed joints (Shehata et al. 2009). Horseradish is best known to cure scurvy, due to its high vitamin C content (Wedelsback Bladh and Olsson 2011).

In Eastern Europe (Austria, Bulgaria, Romanian and Russia), grated horseradish roots or leaves are put in a cloth (sometimes with alcohol or vinegar) and applied to the skin to ease rheumatic pain and to the head to soothe headaches (Sampliner and Miller 2009). Roots are mixed with vinegar, salt and sugar and taken for lowering blood pressure. The root extract is applied to the throat to ease breathing problems and to cure sinuses. Grated roots are mixed with *Robinia pseudoacacia* honey and employed for coughs and bronchitis.

In the community of Russlanddeutsche (Germans from Russia) living in Künzelsau (Germany), it was reported that the Russian sauerkraut, used as an important home medicine for treating flu and liver disease, contained horseradish among other herbs (Pieroni and Gray 2008). In the Basilicata region (South Italy), horseradish leaves and roots have been traditionally used as a remedy for rheumatism, headaches, sinusitis, coughs and bronchitis (Sarli et al. 2012). Added to water, vinegar, salt and sugar or aromatised with dill and bay leaves and pickled tomatoes, horseradish is also used as a remedy for treating drunkenness. Leaves are added to dog food, for its antimicrobial activity (Pieroni et al. 2004; Pieroni and Quave 2005; Sarli et al. 2012).

In America, the Cherokees used horseradish as an abortifacient for obstructed menses, to treat rheumatism, as a remedy for cold and asthma, as a urinary aid for gravel (kidney stones), as a diuretic, as a gastrointestinal aid to improve digestion and to treat mouth and tongue ailments (Moerman 1998, 2009). The Ontario and Delaware natives used the leaf poultice as an analgesic for neuralgia. The Iroquois used an infusion of pulverised roots for the blood and plant infusion for diabetes. The Mohegans applied leaf poultice externally to cheeks for toothache.

Other Uses

Horseradish has insecticidal and nematicidal properties. Of 40 plant essential oils tested for insecticidal activity against larvae of *Lycoriella ingénue* using a biofumigant assay, horseradish, anise and garlic oils showed the most potent insecticidal activities among the plant essential oils. At 1.25 µL/L, horseradish, anise and garlic oils caused 100, 93.3 and 13.3 % mortality (Park et al. 2006). One compound from horseradish, allyl isothiocyanate, was found to be the most toxic with LC50 value of 0.15 µL/L. Studies found that allyl isothiocyanate obtained from *A. rusticana* may be an alternative to phosphine and methyl bromide against the four major pest species of stored products, maize weevil *Sitophilus zeamais*, lesser grain borer *Rhyzopertha dominica*, *Tribolium ferrugineum* and book louse *Liposcelis entomophila* (Wu et al. 2009). *A. rusticana* essential oil containing 97.81 % of allyl isothiocyanate was active against different life stages of *Plodia interpunctella* and adults of *Sitophilus zeamais* (Chen et al. 2011). The results indicated that it may be possible to achieve toxicity levels similar to those of standard chemical fumigants through the applications of essential oils from *A. rusticana*.

Aissani et al. (2013) found that the methanol–aqueous extract of fresh horseradish roots had nematicidal activity against second stage (J2) *Meloidogyne incognita* with EC_{50} of 251 mg/L after 3 days exposure. Allyl isothiocyanate was the most abundant compound and in pure form induced J2 paralysis with an EC_{50} of 52.6 and 6.6 mg/L after 1 hour and 3 days of incubation.

A pilot scale testing demonstrated that minced horseradish roots (1:10 roots to swine slurry ratio), with calcium peroxide (CaO_2 at 34 mM) or hydrogen peroxide (H_2O_2 at 68 mM), could be used for the complete removal of phenolic odorants (with a detection limit of 0.5 mg/L) from the swine slurry; also horseradish could be recycled (reused) five times while retaining significant reduction in the concentration of phenolic odorants (Govere et al. 2007).

The structure and function of horseradish peroxidase offer the opportunity to develop engineered enzymes for practical applications in natural product and fine chemical synthesis, medical diagnostics and bioremediation (Veitch 2004). Horseradish peroxidase is used in medical research and analytical techniques and in detoxification of industrial wastewaters (Wedelsback Bladh and Olsson 2011). Studies by Taudt et al. (2012) demonstrated that horseradish stems could be used in the development of natural fibre-reinforced polymers (NFRPs) as in the design of automotive exterior and interior parts.

Comments

Sampliner and Miller (2009) hypothesised that *Armoracia rusticana* is a species known only from cultivation and that cultivated *A. rusticana* populations were derived from natural populations of either *Armoracia macrocarpa* or *Armoracia sisymbrioides*.

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Brassica napus var. *napobrassica*

Scientific Name

***Brassica napus* var. *napobrassica* (L.) Reichenbach**

Synonyms

Brassica oleracea var. *napobrassica* L., *Brassica campestris* L. var. *napobrassica* (L.) DC., *Brassica napobrassica* (L.) Miller, *Brassica napus* subsp. *napobrassica* (L.) Hanelt, *Brassica napus* var. *edulis* Delile, *Brassica napus* var. *rapifera* Metzger, *Brassica rutabaga* DC. ex H. Léveillé

Family

Brassicaceae

Common Names

Eddie, Neep, Rutabaga, Swede, Swede Turnip, Swedish Turnip, Wax Turnip, Yellow Turnip

Vernacular Names

Chinese: Man Jing Gan Lan
Czech: Tořna
Danish: Kålroe
Dutch: Koolraapen
Finnish: Lanttu
French: Chou-Navet, Navet De Suède, Rutabaga
German: Kohlrübe, Steckrübe, Wruke
Hungarian: Svéd Karórépa
Italian: Navete, Navone, Rapaccio
Japanese: Rutabaga, Suwhēden-Kabu
Norwegian: Kålrot, Kålrabi
Portuguese: Nabo
Polish: Brukiew
Russian: Brjukva
Scots: Neep, Tumshie
Spanish: Col Nabo, Colinabo, Nabo
Swedish: Kålrot

Origin/Distribution

Brassica napus is native to Europe but not known in the wild; it perhaps evolved in the sixteenth century as an allotetraploid derived from wild cabbage *Brassica oleracea* and turnip *Brassica rapa* (Cheo et al. 2001). Two varieties of *Brassica napus* are recognised: var. *napus* and var. *napobrassica* (rutabaga or swede). Rutabagas are grown for human and animal consumption (Undersander et al. 1992). Rutabagas have been introduced to North America, North Asia and elsewhere including Australia and New Zealand. It is cultivated occasionally in the highlands in Southeast Asia.

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Agroecology

Rutabaga is adapted to a humid cool climate as found in the Mediterranean to subtemperate areas. Optimum temperatures for growth are 15–20 °C. Rutabaga plants are both cold hardy and drought tolerant. They thrive best in a moderately deep, moderately well-drained, fertile and slightly acid sandy loams, loams and clay loams with pH 6–6.8 in full sun.

Edible Plant Parts and Uses

The edible tuberous root is eaten raw or cooked. In Finland, rutabaga is boiled, baked, roasted, used as a flavour enhancer for soups and roasted served with meat dishes as the main ingredient in the popular Christmas dish swede casserole 'lanttulaatikko'. Uncooked, rutabaga is thinly julienned as a side dish or used in a salad.

In Sweden and Norway, rutabaga is cooked and mashed with potatoes, carrots with butter, cream or milk to produce a puree called 'kålrot/kålrabistappe' or 'rotmos', respectively. In Norway *kålrot/kålrabistappe* is an essential accompaniment to many festive dishes including salted herring, *smalahove* and *pinnekjøtt*.

Scots boil and mash rutabagas and potatoes separately to produce 'tatties and neeps' served traditionally with the Scottish national dish of 'haggis'. Neeps are also mashed with potatoes to make 'clapshot', a traditional Scottish dish, and used in soups and stews. In Yorkshire and Lincolnshire, rutabagas are mashed with carrots and eaten as accompaniment to the traditional Sunday roast.

Canadians used rutabagas as filler in foods such as mincemeat and Christmas cake or as a side dish with Sunday dinner. Americans consumed rutabagas mainly in stews and casseroles and served mashed with potatoes or baked in a pasty.

Botany

A biennial, glabrous, glaucous herb, 30–150 cm high with a fleshy, napiform or globose root. The 'root' consists of the hypocotyl – the plant part that lies between the true root and the first seedling leaves (cotyledons) – and the base of the leafy stem. The storage root may be purple, white or yellow or greenish tinged, with yellowish flesh (sometimes yellowish-white flesh) (Plates 1 and 2). Stems erect, branched above. The basal and lowermost cauline leaves long petiolate; petiole to 15 cm; glaucous (bluish green), leaf blade ovate, oblong or lanceolate in outline, 5–25(−40) by 2–7(−10) cm, pinnately lobed or lyrate. Upper leaves sessile, lanceolate, ovate or oblong, to 8 by 3.5 cm, base amplexicaul, auriculate, margin entire or repand. Flowers not raised above the unopened buds on the raceme. Sepals oblong, ascending or rarely suberect. Petals pale

Plate 1 (**a**, **b**) Globose rutabaga cultivars

Plate 2 Napiform-shaped rutabaga

creamy yellow, broadly obovate, apex rounded; claw distinct 5–9 mm. Stamens 6, filaments 5–10 mm, anthers oblong. Fruit linear, 4–11 cm × 2.5–5 mm, terete or slightly 4 angled, sessile, divaricate or ascending. Seeds dark brown or blackish, globose, 1–2 mm to 3 mm across, minutely reticulate.

Nutritive/Medicinal Properties

Proximate nutrient composition (per 100 g edible portion) of raw rutabaga (*Brassica napus* var. *napobrassica*) tuber was reported as water 89.66 g; energy 36 kcal (151 kJ); protein 1.20 g; total lipid 0.20 g; ash 0.81 g; carbohydrate 8.13 g; total dietary fibre 2.5 g; total sugars 5.60 g; minerals, Ca 47 mg, Fe 0.52 mg, Mg 23 mg, P 58 mg, K 337 mg, Na 20 mg, Zn 0.34 mg, Cu 0.040 mg, Mn 0.170 mg and Se 0.7 µg; vitamins, vitamin C 25 mg, thiamine 0.090 mg, riboflavin 0.040 mg, niacin 0.700 mg, pantothenic acid 0.160 mg, vitamin B6 0.100 mg, total folate 21 µg, total choline 14.1 mg, vitamin A 2 IU, β-carotene 1 µg, vitamin K (phylloquinone) 0.3 µg and vitamin E (α-tocopherol) 0.30 mg; total saturated fatty acids 0.027 g, 16:0 (palmitic acid) 0.024 g and18:0 (stearic acid) 0.003 g; total monounsaturated fatty acids 0.025 g and 18:1 undifferentiated (oleic acid) 0.025 g; total polyunsaturated fatty acids 0.088 g, 18:2 undifferentiated (linoleic acid) 0.035 g and 18:3 undifferentiated (linolenic acid) 0.053 g; and amino acids, tryptophan 0.013 g, threonine 0.046 g, isoleucine 0.050 g, leucine 0.038 g, lysine 0.039 g, methionine 0.010 g, cystine 0.011 g, phenylalanine 0.031 g, tyrosine 0.023 g, valine 0.048 g, arginine 0.148 g, histidine 0.030 g, alanine 0.033 g, aspartic acid 0.087 g, glutamic acid 0.142 g, glycine 0.027 g and serine 0.035 g (USDA ARS 2014).

Rutabaga was reported to contain the flavone apigenin (mean 3.85 mg, maximum 15.4 mg/100 g) (Hertog et al. 1992; Lugasi and Hovari 2000) and flavonols myricetin (mean 2.13 mg, max 8.54 mg/100 g) (Hertog et al. 1992; Lugasi and Hovari 2000), kaempferol (mean 0.32 mg, max 2.27 mg/100 g) (Hertog et al. 1992; Lugasi and Hovari 2000; Huang et al. 2007) and quercetin (mean 0.05 mg, max 0.32 mg/100 g) (Hertog et al. 1992; Lugasi and Hovari 2000; Huang et al. 2007).

Major glucosinolates found in rutabaga roots were 2-hydroxy-3-butenyl glucosinolate, 2-phenylethyl glucosinolate, 3-indomethyl glucosinolate, 4-(methylthio)butyl glucosinolate (Carlson et al. 1981). Glucosinolates generally were higher in roots of rutabaga than in those of turnip (Ju et al. 1980). Accumulation of different glucosinolates in roots of both species occurred at different times during the growing season in the sequence after seeding: indolyl glucosinolates yielding ionic thiocyanate at the 2-week stage, glucosinolates yielding volatile isothiocyanate hydrolysis products at the 4-week stage and 2-hydroxy-3-butenyl glucosinolate (progoitrin) yielding 5-vinyl-oxazolidine-2-thione (goitrin) at the 6- or 8-week stage. Mean total glucosinolate content of rutabaga and turnip grown on organic soil was 15 % and 38 % higher than those grown on loam soil, respectively. The contents of goitrin and volatile isothiocyanates were inversely correlated in the seed of both species. Nine glucosinolates were found in rutabaga grown on soil capped over a coal fly ash landfill or on normal clay and silt loam soil (Anderson et al. 1990). Progoitrin (2-hydroxy-3-butenyl glucosinolate) and neoglucobrassicin (1-methoxy-3-indolylmethyl glucosinolate) were the most abundant glucosinolates found. Progoitrin and three other minor glucosinolates were present in the natural soil-grown rutabaga in greater

amounts than in that grown in fly ash soil. However, fly ash-grown rutabaga contained comparatively greater levels of glucobrassicin (3-indolylmethyl glucosinolate) and neoglucobrassicin, the major glucosinolate present.

Glucosinolate-derived nitrile and isothiocyanate of rutabaga and turnip cultivars (μg/g FW) were 1-cyano-4-methylthiobutane, 3-phenylpropionitrile, 1-cyano-5-methylthiopropane, 4-ethylthiobutyl isothiocyanate, 2-phenylethyl isothiocyanate, goitrin and 5-methylthiopentenyl isothiocyanate, and also methyl palmitate was detected (Mullin et al. 1980). Thiocyanate ions, normally formed from isothiocyanates, had been found to be derived from indolyl glucosinolate. The goitrin content of rutabaga and turnip was found to vary between 9 and 124 μg/g. S-methyl and phenylethyl isothiocyanates and nitriles were major contributors to the flavour and aroma of rutabaga and turnip. Autolysis reduced the concentration of glucosinolate hydrolysis products and was particularly effective in reducing goitrin content in rutabaga (Mullin 1980). During low temperature storage (0 and 10 °C for 8 weeks) of field-harvested rutabaga roots, the total sugar concentration (sucrose, fructose and glucose) increased rapidly during the first 2 weeks and then levelled off (Shattuck et al. 1991). The total sugar concentration in roots was not influenced by storage temperature. The low temperature treatment (0–12 °C for 11 days) of plants resulted in a 10 % increase in the total sugar concentration in roots. Low temperature altered the concentration of several glucosinolates in peeled root and peeled tissues, but did not induce a qualitative change in the glucosinolate profile. Changes in the glucosinolate concentrations at low temperature were dependent on the treatment, temperature and root tissue examined.

Only one of the 14 root glucosinolates detected from swede roots (*Brassica napus* subsp. *rapifera*), 3-indolylmethyl glucosinolate, rose significantly with increasing levels of turnip root fly, *Delia floralis* attack (Hopkins et al. 1998). Swede roots that had been damaged by *D. floralis* contained approximately three times the concentration of total indolyl glucosinolates of control roots. This change was strongly influenced by a fourfold increase in the concentration of 1-methoxy-3-indolylmethyl glucosinolate. The total glucosinolate concentration found in swede roots remained unchanged overall as a result of a fall in the concentration of five of the aliphatic glucosinolates, which balanced the rise in aromatic glucosinolates.

Three new phytoalexins, named isalexin, brassicanate A and rutalexin, were isolated together with five known phytoalexins, brassinin, 1-methoxybrassinin, spirobrassinin, brassicanal A and brassilexin, from rutabaga (*Brassica napus* L. subsp. *rapifera*) tubers (Pedras et al. 2004). Biosynthetic studies using tetra- and penta-deuterated precursors established indolyl-3-acetaldoxime and brassinin as precursors of brassicanate A and rutalexin and cyclobrassinin as a biosynthetic precursor of rutalexin. Tryptamine was found not to be a precursor of rutabaga phytoalexins.

The amount of wax extracted from the periderm of rutabaga tuber was 14.7 mg/kg of chloroform-extractable material, equivalent to 59 % weight of chloroform extract or 5 $\mu g/cm^2$ wax/surface area (Espelie et al. 1980). The composition of rutabaga wax comprised 4.7 % hydrocarbon, 1.8 % wax ester, 21 % fatty alcohol, 49 % fatty acids and 23 % unknown component. Chain-length distribution of the fatty alcohols, fatty acids, ω-hydroxy acids and dicarboxylic acids in the polar fraction of the $CHCl_3$ extract of rutabaga storage organ was 3.28 %, 3.37 %, 0.24 % and 0.15 %, respectively.

Total glucosinolates in rutabaga leaves amounted to 15.14 μmol/g DW made up of aliphatic glucosinolates: progoitrin 5.46 μmol, epiprogoitrin 0.04 μmol, sinigrin 0.02 μmol, gluconapoleiferin 1.12 μmol, glucoalyssin 1.88 μmol, gluconapin1.22 μmol, glucobrassicanapin 2.54 μmol; indole glucosinolate: glucobrassicin 1.16 μmol, 4-hydroxyglucobrassicin 0.21 μmol, neoglucobrassicin 1.20 μmol, 4-methoxyglucobrassicin 0 μmol; and aromatic glucosinolate: gluconasturtiin 0.36 μmol (Velasco et al. 2008).

Total glucosinolates in rutabaga seeds amounted to 107.70 μmol/g DW comprising aliphatic glucosinolates: progoitrin 71.57 μmol, epiprogoitrin 1.46 μmol, sinigrin 0.53 μmol,

gluconapoleiferin 1.46 μmol, glucoalyssin 1.26 μmol, gluconapin 22.13 μmol, glucobrassicanapin 2.43 μmol; indole glucosinolates, glucobrassicin 0.15 μmol, 4-hydroxyglucobrassicin 5.61 μmol, neoglucobrassicin 0 μmol, 4-methoxyglucobrassicin 0.39 μmol; and aromatic glucosinolate: gluconasturtiin 0.70 μmol (Velasco et al. 2008).

In black-seeded and yellow-seeded *B. napus* var. *napus*, sinapine, sinapic acid and 1,2-disinapoylglucose were found as the most abundant phenolic compounds in the seeds and 16 flavonoids were also identified including (−)-epicatechin, five monocharged oligomers of (−)-epicatechin ([DP 2](−), [DP 3](−), [DP 4] [DP 2](−) B2 and [DP 2](−) B5), quercetin, kaempferol, isorhamnetin-dihexoside, kaempferol-sinapoyl-trihexoside, isorhamnetin-sinapoyl-trihexoside, isorhamnetin-hexoside-sulfate and isorhamnetin-3-*O*-glucoside (Jiang et al. 2013). Most of the flavonoids accumulated with seed development, whereas some rapidly decreased during maturation. The content of these flavonoids was lower in the yellow-seeded materials than in the black seeds. Additionally, variations of insoluble procyanidin oligomers and soluble phenolic acids were observed among the varieties. A total of 91 flavonoids and hydroxycinnamic acid derivatives were detected, including 39 kaempferol derivatives, 11 isorhamnetin derivatives, 5 quercetin derivatives, 6 flavanols and their oligomers and 30 hydroxycinnamic acid derivatives in *Brassica napus* var. *napus* seeds (Shao et al. 2014).

Baenas et al. (2014) in their study of the use of bioelicitors to enrich ready-to-eat sprouts in health-promoting glucosinolates found that phytohormones methyl jasmonate and jasmonic acid and oligosaccharides glucose and sucrose acted as effective elicitors, increasing the total glucosinolate glucobrassicin content of rutabaga sprouts from 29.6 to 186 mg/100 g.

Antioxidant Activity

Studies showed that rutabaga sprouts had significantly higher antioxidant activity than seeds and roots, which may result from different contents of polyphenols (Pasko et al. 2013).

Anticancer Activity

The major physiologically active compounds derived from glucosinolates from *Brassica* crops were found to be isothiocyanates, nitriles and oxazolidine-2-thiones, and many of them possessed anticarcinogenic activities (Fenwick and Heaney 1983). Many isothiocyanates, derived from the hydrolysis of glucosinolate precursors of cruciferous vegetables, exhibited anticarcinogenic activity by reduced activation of carcinogens and increasing their detoxification. Recent studies showed that they exhibited antitumour activity by affecting multiple pathways including apoptosis, MAPK (mitogen-activated protein kinase) signalling, oxidative stress and cell cycle progression (Wu et al. 2009). A number of epidemiological studies have identified an inverse association between consumption of *Brassica* leaf and root vegetables and the risk of colon and rectal cancer (Verkerk et al. 2009). Yang et al. (2002) demonstrated the chemopreventive efficacy of the N-acetylcysteine conjugates of phenethyl isothiocyanate (PEITC) and benzyl isothiocyanate (BITC) administered in the mice diet after a single dose of benzo(a)pyrene for lung tumorigenesis and provided the first in-vivo evidence that activation of MAP kinases, AP-1 transcription factors and p53 phosphorylation and the induction of apoptosis may be involved in the chemopreventive activity of these compounds. In-vitro studies showed that phenethyl isothiocyanate (PEITC) was a stronger inducer of apoptosis than sulphoraphane as it covalently bind to cellular proteins in human non-small lung cancer cells more strongly than sulphorane (Mi et al. 2007). Rutabaga extracts (especially 8-day sprouts) inhibited the tumour cell line HepG2 proliferation and had a slight effect on the normal mammalian CHO-K1 culture (Pasko et al. 2013). The extracts exerted cell death via apoptosis. The results suggested that one of the biological activities of rutabaga was antiproliferative and pro-apoptotic potential specific to tumour cells.

Goitrogenic Issues

One of the most potent goitrogens, 5-vinyl-oxazolidine-2-thione (goitrin), had been found to be derived from the hydrolysis of 2-hydroxy-3-butenyl glucosinolate (progoitrin), a predominant glucosinolate in rutabaga (Chong et al. 1982). Goitrin is a potent antithyroid agent; it had been reported to reduce the production of thyroid hormones such as thyroxine (McMillan et al. 1986). Administration of goitrin to rats was found to cause hyperplasia of the thyroid (Carroll 1949).

Swede was found to contain undesirable glucosinolates such as sinigrin (tr, 0.4 μmol/g DM), 1.8–5.6 progoitrin (μmol/g) and gluconapoleiferin (tr, 1.8 μmol/g) (Olsson and Jeppsson 1984). Sinigrin and its degradation product are both bitter substances in *Brassica* vegetables which included swede. Progoitrin and gluconapoleiferin are tasteless, but their hydrolytic products, oxazolidinethiones, are very bitter. They are also goitrogenic substances and may contribute to hypothyroidism even if there is enough iodine in the diet.

Other Uses

Brassica napus is one of the most important sources of seed vegetable oil. The seed oil is also used in the manufacture of lubricants, grease, lacquers, varnishes, soap, resins, nylon, plastics, insect repellents, stabilisers and pharmaceuticals. Rutabagas with yellow flesh, which have a bitter taste, are usually used for human nutrition, while those with whitish flesh are used as fodder crop. Rutabaga is also used as forage for livestock.

Comments

Rutabagas, or swede turnips, are the large, yellow-fleshed roots commonly referred to as 'table' turnips. The yellow-fleshed types are preferred over white-fleshed types. Sinskaja (1928) used the shape of the hypocotylous tuber and its skin colour and the shape of the leaves to describe different varieties (Šebalina and Sazonova 1985).

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Brassica oleracea (Gongylodes Group)

Scientific Name

***Brassica oleracea* L. (Gongylodes Group)**

Synonyms

Brassica caulorapa (DC) Pasquale, *Brassica oleracea* subsp. *caulorapa* Metzg., *Brassica oleracea* var. *caulorapa* (DC.) Alef., *Brassica gongylodes* (L.) Mill., *Brassica gongylodes* (L.) Mill. subsp. *asiatica* Lizg., *Brassica gongylodes* (L.) Mill. subsp. *gongylodes* Lizg., *Brassica oleracea* subsp. *gongylodes* (L.) Schübl. & Mart., *Brassica oleracea* L. var. *gongylodes* L., *Brassica oleracea* convar. *acephala* (DC.) Alef. var. *gongylodes*, *Brassica rupestris* subsp. *gongylodes* (L.) Janchen

Family

Brassicaceae

Common Names

German cabbage, Kohlrabi, Knolknol, Stem Turnip, Cabbage Turnip, Turnip cabbage, Turnip-Stemmed Cabbage, Hungarian Turnip, Turnip Kale

Vernacular Names

Afrikaans: Knolkool, Knolraap, Koolraap
Austrian: Kohlrübe
Belarusian: Kalrabi
Bulgarian: Kohlrabi
Chinese: Pie Lan, Cai Tou, Jie Lan Tou, Gai Lan Tou, Qiu Gan Lan, Qiu Jing Gan Lan, Bo Lan
Catalan: Col-I-Nap
Croatian: Keleraba, Korabica
Czech: Brukev Kedluben, Kedluben
Danish: Kålrabi, Kaalrabi, Knudekål, Glaskålrabi
Dutch: Koolrabi, Bladkoolachtigen
Esperanto: Tigobrasiko
Estonian: Koolrabi, Nuikapsas
Finnish: Kaalirapi, Kyssäkaali
French: Chou-Rave, Chou Rave, Chou Navet
German: Kohlrabi, Rübkohl
Hungarian: Karalábé
India: Olkabi, Olkobi (Assamese), Ganth Gobi, Olkapi, Olkopi (Bengali), Knol-Knol (English), Nookal (Hindi), Gedde Kosu, Navilu Kosu (Kannada), Ganth Gobi, Moonji, Monji Haak (Kashmiri), Alkul, Navalkol (Maharashtra)
Italian: Cavolo Rapa, Col Rabano
Japanese: Kyuukei Kanran, Kuki Kanran, Koorurabii, Kabu Kanran, Kabura Habotan, Ryukyu Kanranp
Jèrriais: Kohlrabi
Korean: Jul-Gi-Yang-Bae-Chu
Macedonian: Kelerába

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Norwegian: Knutekål
Polish: Kalarepa
Portuguese: Couve Rábano, Couve Nabo
Romanian: Gulie
Russian: Kol'rabi
Serbian: Keleraba
Slovenščina: Koleraba
Spanish: Col Rábano, Coli Rábano, Colirrábano, Colinabo
Swedish: Kålrabbi
Vietnamese: Su Hào
Volapük: Kaulabrasid

Origin/Distribution

The origin of kohlrabi is reported to be in north-western Europe, where it was developed from marrow-stem kale, a fodder crop with a thickened stem. It was grown by the ancient Romans and the gardeners of the emperor Charlemagne. Today it is cultivated globally, including the tropics up in the cool mountainous areas. The Mediterranean area and Western Europe are the main areas of cultivation and centres of diversity. Kohlrabi is a popular vegetable in Europe, Asia, northern USA and Canada.

Agroecology

Kohlrabi is adapted to temperate climate but is grown in the cool highlands in the subtropics and tropics. Kohlrabi is more tolerant of heat and drought than most of the cabbage relatives and it can withstand frosts down to at least −12 °C. It flourishes in full sun in well-drained, fertile soil rich in organic matter. It does best in full sun, but kohlrabi can stand a little shade and it needs frequent watering. Kohlrabi is fast growing, producing harvest-sized, above-ground, subglobose corms (tuberous stem) within 50–70 days, depending on the variety.

Wiebe et al. (1992) found that temperatures below 11 °C supported tuber modification (vernalisation), while temperatures above 11 °C inhibited it (devernalisation). Devernalisation increased with increasing temperature.

Edible Plant Parts and Uses

The young, swollen, fleshy, subglobose kohlrabi stem base is peeled and eaten raw served with a little salt and vinegar. It tastes like a combination of mild turnip and sweet apple. It has a mild cabbage flavour or a very sweet turnip with celery or nutty overtones. When finely grated it makes a good addition to mixed salads and, when cooked, boiled or steamed, is an excellent vegetable. Kohlrabi can be eaten as baked fries or wedges. Leaves are cooked as a vegetable or the young leaves can also be added to salads.

Kohlrabi is an important part of the Kashmiri diet and one of the most commonly cooked foods. It is prepared with its leaves and served with a light gravy and eaten with rice. Kohlrabi stem is used in the vegetarian curry *ganth gobi sabzi*, kohlrabi stew (*Monji Kalia*) or fried kohlrabi curry (*Dum Monji).* The swollen stem and leaves are also used together in a dish called *Monji Haak*.

Botany

An erect, glabrous annual or biennial herb up to 50 cm tall at the mature vegetative stage, with unbranched, highly shortened, swollen, subglobose to globose, fleshy corm or bulbotuber-like stem up to 12 cm in diameter, pale greenish-white, purple and strongly branched root system (Plates 1, 2 and 3). Leaves alternate, simple or with some small side lobes at base; exstipulate; all leaves with distinct, slender, terete petiole; blade ovate or oblong-elliptical in outline, 20–28 cm long by 14–16 cm wide, irregularly incised, blue green. Inflorescence, a terminal paniculate raceme. Flowers bisexual, regular, 4-merous; pedicel up to 2 cm long; sepals oblong, about 1 cm long, erect; petals obovate, 1.5–2 cm long, clawed, pale to bright yellow or yellowish white; stamens 6; ovary superior, cylindrical, 2-loculed, stigma globose. Fruit, a linear or curved silique 5–10 cm long by 5 mm wide, with a tapering beak 5–15 mm long, dehiscent, containing up to 30 seeds. Seeds globose, 1.5–2 mm across, finely reticulate, dark brown.

Plate 1 Kohlrabi plant habit

Plate 2 Harvested kohlrabi

Plate 3 Purplish kohlrabi

Nutritive/Medicinal Properties

Kohlrabi swollen stems and leaves are rich in vitamins, essential minerals and antioxidants. The proximate value per 100 g edible portion of raw kohlrabi stem had been reported as: water 91 g; energy 27 kcal (113 kJ); protein 1.7 g; total lipid 0.01 g; ash 1 g; carbohydrate 6.2 g; total dietary fibre 3.6 g; total sugars 2.6 g; minerals, Ca 24 mg, Fe 0.04 mg, Mg 19 mg, P 46 mg, K 350 mg, Na 20 mg, Zn 0.03 mg, Cu 0.129 mg, Mn 0.139 mg and Se 0.7 µg; vitamins, vitamin C 62 mg, thiamine 0.05 mg, riboflavin 0.2 mg, niacin 0.4 mg, pantothenic acid 0.165 mg, vitamin B6 0.15 mg, total folate 16 µg, total choline 12.3 mg, vitamin A 36 IU or 2 µg RAE, vitamin E (α-tocopherol) 0.48 mg, vitamin K (phylloquinone) 0.1 µg, β-carotene 22 µg, total saturated fatty acids 0.013 g, 16:0 (palmitic acid) 0.011 g,18:0 (stearic acid) 0.001 g, total monounsaturated fatty acids 0.007 g, 18:1 undifferentiated (oleic acid) 0.007 g, total polyunsaturated fatty acids 0.048 g, 18:2 undifferentiated (linoleic acid) 0.020 g and 18:3 undifferentiated (linolenic acid) 0.026 g; and amino acids, tryptophan 0.010 g, threonine 0.049 g, isoleucine 0.078 g, leucine 0.067 g, lysine 0.056 g, methionine 0.013 g, cystine 0.007 g, phenylalanine 0.039 g, valine 0.05 g, arginine 0.105 g and histidine 0.019 g (USDA, ARS 2014). Kohlrabi with a vitamin C content of 47–66 mg/100 g was than Swede turnip (14 mg), Hamburg parsley 15 mg and turnip 18–24 mg (Warne 1942).

Duke and Ayensu (1985) reported on proximate nutrient composition of the stem and leaf as stem (fresh weight per 100 g edible portion): water 90.3 %, energy 29 cal, protein 2 g, fat 0.1 g, carbohydrate 6.6 g, fibre 1 g, ash 1 g, Ca 41 mg, P 51 mg, Fe 0.5 mg, Na 8 mg, K 372 mg, vitamin A 20 mg, thiamine 0.06 mg, riboflavin 0.04 mg, niacin 0.3 mg and vitamin C 66 mg. Leaves (dry weight per 100 g edible portion): energy 320 cal, protein 23.5 g, fat 2.5 g, carbohydrate 62.5 g, fibre 13 g, ash 10.5 g, Ca 430 mg, P 450 mg, Fe 10.5 mg, Na 80 mg, K 3,100 mg, vitamin A 15,000 mg, thiamine 0.6 mg, riboflavin 0.7 mg, niacin 4.5 mg and vitamin C 670 mg.

Among the proximate compositions, the crude fat of kohlrabi peel contained lower than that of kohlrabi flesh, while the contents of carbohydrate and the crude protein were higher in the kohlrabi peel (Cha et al. 2013). Total free sugar content of kohlrabi flesh was higher than that of the peel, and the major free sugars of the flesh kohlrabi and peel were identified as fructose and glucose. The value of glutamic acid was greater in amino acids of kohlrabi flesh than kohlrabi peel, and the contents of total amino acids and essential amino acids were higher in kohlrabi peel compared with kohlrabi flesh. Kohlrabi flesh also contained a higher level of unsaturated fatty acids than kohlrabi peel. The contents of organic acid were higher in kohlrabi peel, and the level of oxalic acid was the highest in both parts. The vitamin C contents of kohlrabi flesh and peel were 231.36 mg/100 g and 402.75 mg/100 g, respectively. The mineral content of the kohlrabi peel was higher than that of the flesh and the mineral contents of the flesh and peel in the order of K>Ca>Mg>Na. Overall, the contents of total amino acid, essential amino acid, organic acid, vitamin C and mineral were higher in kohlrabi peel, and the free sugar and unsaturated fatty acid contents were higher in kohlrabi flesh.

Kohlrabi was reported to contain total phenolics 44.9 mg GAE/100 g fresh mass and total flavonoids mg 8.9 mg CE/100 g fresh mass (Marinova et al. 2005). Flavonoid aglycones found in kohlrabi included luteolin 1.3 mg, kaempferol 2.4 mg and quercetin 0.4 mg (Lugasi and Hovari 2000). The insoluble fibre lignins in kohlrabi were classified as balanced lignins with guaiacyl–syringyl G–S ratio (0.3 < G–S ratio <3) (Bunzel et al. 2005).

The kohlrabi had harder texture than the radish and contained less reducing sugars, cellulose and pectin than the radish (Choi et al. 2010). The total amino acid content in the kohlrabi was 2.7-fold higher than that in the radish; in particular the hydrophilic amino acids including aspartate, glutamate and arginine were about threefold higher in the kohlrabi, suggesting that the kohlrabi was more palatable than the radish. The total contents of glucosinolates in the radish in inner and outer section were higher than those in the kohlrabi, by 12.4- and 28.5-fold, respectively. In a sensory test, the kohlrabi was evaluated less bitter and pungent than the radish. The kohlrabi contained more glucoraphanin, an anticancer compound, than the radish.

The following glucosinolate (GS) content (μmol/100 g FW) was determined in kohlrabi: 86.1 μmol total GS, 9.7 μmol 3-methylthiopropyl GS, 2.3 μmol 3-methylsulfinylpropyl GS, 0.3 μmol 2-hydroxy-3-butenyl GS, 33.6 μmol 4-methylthiobutyl GS, 4.3 μmol 4-methylsulfinylbutyl GS, 1.8 μmol 2-phenylethyl GS and 27.7 μmol 3-indolylmethyl GS (Carlson et al. 1987). Ally GS and 3-butenyl GS were not detected. The predominant GSs in kohlrabi were 4-methylthiobutyl GS and 3-methylthiopropyl GS. The seed was found to contain higher levels of the corresponding sulfinyl compounds than of the two methylthio compounds, and 4-methylsulfinylbutyl GS was the GS present in the largest amount in the seed. The glucosinolates in 9 *Brassica* vegetable seeds including kohlrabi were significantly higher than in sprouts, and day 8 of germination was considered the optimum for consumption of edible sprouts (Baenas et al. 2012). The sprouts with higher concentrations of glucosinolates in 8-day-old sprouts were white mustard, turnip and kohlrabi (circa 815, circa 766 and circa 653 mg/100 g FW, respectively). The importance of dietary sulforaphane in helping maintain good health continues to gain support within the health-care community and awareness among US consumers (West et al. 2004). They found that crucifer seeds including kohlrabi to be good sources for obtaining glucoraphanin, the natural precursor to sulforaphane, owing to a higher concentration of glucoraphanin and the relative ease of processing seeds as compared to vegetative parts. The major glucosinolates identified in kohlrabi by Ciska et al. (2000) were glucoraphanin, glucoerucin, glucoiberin and glucobrassicin.

Park et al. (2013) found that after 10-days storage at 4 °C, total glucosinolates (GSs) in white kohlrabi increased markedly from 16.72 to 48.35 μmol/g DW. The highest amount of GS found was glucobrassicanapin (4-pentyl GS), followed by glucoerucin (4-methylthiobutyl GS) and

sinigrin (2-propenyl GS). Other GSs present included progoitrin (2-hydroxy-3-butenyl GS), glucoraphanin (4-methylsulfinylbutyl GS), glucobrassicin (3-indoylmethyl GS), 4-methoxyglucobrassicin (4-methoxy-3-indoylmethyl GS) and neoglucobrassicin (1-methoxy-3-indoylmethyl GS). GSs glucoalyssin (5-methylsulfinylpentyl GS), gluconapin (3-butenyl GS) and gluconasturtiin (2-phenylethyl GS) were not detected in white kohlrabi. In red kohlrabi, TGSs increased sharply after 1 and 3 days and then decreased sharply after 10 days, registering an overall slight decline from 53.71 μmol/g DW at day 0 to 50.3 μmol/g DW after 10-day storage. This trend was observed for all GSs present. The highest amount of GS found was glucobrassicanapin (4-pentyl GS), followed by glucoerucin (4-methylthiobutyl GS) and glucobrassicin (3-indoylmethyl GS). Other GSs found in red kohlrabi included progoitrin (2-hydroxy-3-butenyl GS), glucoraphanin (4-methylsulfinylbutyl GS), glucoalyssin (5-methylsulfinylpentyl GS), 4-methoxyglucobrassicin (4-methoxy-3-indoylmethyl GS), gluconasturtiin (2-phenylethyl GS) and neoglucobrassicin (1-methoxy-3-indoylmethyl GS). GSS not found were sinigrin (2-propenyl GS) and gluconapin (3-butenyl GS). Vicas et al. (2013) found 4.89 μmol/g dw of total glucosinolate content in kohlrabi, predominated by indolyl glucosinolates (glucobrassicin, neoglucobrassicin, 4-methoxyglucobrassicin).

Analysis of the skin and flesh of pale green and purple kohlrabis revealed the presence of 8 glucosinolates, 12 anthocyanins, 2 carotenoids and 7 phenylpropanoids (Park et al. 2012). Glucosinolate contents are varied among the different parts and types of kohlrabi. Glucoerucin contents were fourfold higher in the flesh of purple kohlrabi than those in the skin. Among the 12 anthocyanins, cyanidin 3-(feruloyl) (sinapoyl) diglucoside-5-glucoside levels were the highest. Carotenoid levels were much higher in the skins than the flesh of both types of kohlrabi. The levels of most phenylpropanoids were higher in purple kohlrabi than in pale green ones. *Trans*-cinnamic acid content was 12.7-fold higher in the flesh of purple kohlrabi than that in the pale green ones.

The health-promoting properties of *Brassica* vegetables including kohlrabi emanate from isothiocyanates (ITCs) the breakdown products released after hydrolysis of glucosinolates (GSs) by myrosinase. Cutting and chewing of cruciferous vegetables releases the thioglucosidase enzyme myrosinase, which degrades glucosinolates to isothiocyanates and other minor metabolites (Krul et al. 2002).

About 190 μg of aroma components were obtained per gram fresh weight of green kohlrabi, and 83 volatile components (ca 96 % w/w of the sample) were identified (Macleod and Macleod 1990). Sulphur compounds provided a high proportion of kohlrabi volatiles (ca 37 % w/w), with dimethyl trisulfide (ca 25 %) being the major component. Isothiocyanates, derived from glucosinolates, were also important aroma volatiles of kohlrabi. Eight glucosinolates were thus characterised in kohlrabi, the major ones being 4-methylthiobutyl glucosinolate, 3-methylthiopropyl glucosinolate and 2-phenethyl glucosinolate. Two unusual sulphur-containing ketones were also identified, 4-methylthiobutan-2-one and 1-methylthiopentan-3-one. In another study, the major volatile products (ug/100 g fresh mass) from the edible part of kohlrabi were 3-methylthiopropyl ITC (212.94 μg), 4-methylthiobutyl ITC (233.64 μg) and allyl ITC (37.73 μg) (Fischer 1992). The two corresponding organic cyanides 3-methylthiopropyl cyanide and 4-methylthiobutyl cyanide and dimethyl disulfide, dimethyl trisulfide and dimethyl tetrasulfide were also present in high amounts. *n*-Nonenal, (*E*)-2-hexenal, (*E,E*)-2,4-heptadienal and some isothiocyanates of unknown structure appeared in the volatile fraction as minor constituents. The sulphur- and nitrogen-containing components could be related to the enzymatic cleavage (myrosinase) of glucosinolates, naturally occurring precursors in *Brassica* plants. The presence of 3-methylthiopropyl isothiocyanate indicated glucoibervirin as a new precursor in the vegetable part of kohlrabi. The presence of ally ITC in kohlrabi concurred with the findings of Josefsson (1967).

Gawęda and Nizioł-Łukaszewska (2011) found that during 5 months of storage, very low losses of kohlrabi mass were detected. The decrease in dry matter found was between 15 and 18 %. After a brief increase, soluble sugar content that decreased during storage of L-ascorbic acid was well preserved in the kohlrabi, since 90 % remained after storage was completed. The isothiocyanate content changed little, and the vegetable remained a good source of these compounds throughout the storage period. Gerendás et al. (2008) found that the ITC of kohlrabi tubers was dominated by methylthiobutyl ITC (11–1,350 μmol/g DM), followed by sulforaphane (7–120 μmol/g DM), phenylethyl ITC (5–34 μmol/g DM) and allyl ITC (5–38 μmol/g DM), resulting from the hydrolysis of glucoerucin, glucoraphanin, gluconasturtiin and sinigrin, respectively. They found that the concentrations of all ITCs were substantially reduced in response to increasing nitrogen and decreasing sulphur supply.

Four glucosinolates, i.e. glucoraphanin, glucobrassicin, gluconasturtiin and neoglucobrassicin, were identified in the leaves of five kohlrabi genotypes cultivated in Southern Italy (Branca et al. 2013). The glucosinolate profile of the stems and leaves were similar. However, stems showed a lower glucosinolate amount and the presence of glucoerucin. The total polyphenol and ascorbic acid content was slightly higher in the leaves than in the stems. With regard to total anthocyanins, higher values were found in the leaves with respect to the skins, with the exception of cv. CR17.

Infection by the phytopathogenic fungus, *Cladosporium cucumerinum*, elicited the production of the indole phytoalexin 1-methoxyspirobrassinin on kohlrabi (Gross et al. 1994). The phytoalexin could also be elicited abiotically by cuprous chloride.

Both enantiomers of α-aminooxy-β-phenylpropionic acid (AOPP), potent inhibitors of L-phenylalanine ammonia-lyase, and their N-benzyloxycarbonyl (N-BOC) derivatives inhibit anthocyanin formation in seedlings of kohlrabi and red cabbage with little interference with their normal development (Amrhein and Holländer 1979). Kohlrabi seedlings tolerated up to 0.3 mM L-AOPP and N-BOC–L-AOPP without a reduction of fresh weight or chlorophyll content, while anthocyanin was reduced to less than 20 %.

Total phenols per baked biscuit unit fortified with kohlrabi stem flour were calculated after baking (Hassan et al. 2011). The results revealed that total phenols were higher in the leaves as compared to stems in both red and green kohlrabi cultivars. Salicylic acid represented the maximum fraction detected in the green skin kohlrabi stems (56.1 mg/100 g dw), almost double the value in the red cultivar (28.5 mg/100 g dw). Maximum recovery of total phenols was 83.4 and 52.0 mg per 1 biscuit unit (of ca.22 and 18 g) at 15 % and 8 % levels of the added green and red kohlrabi stems in the blend, respectively. Slight changes were recorded in the final baking characteristics due to kohlrabi stem flour addition. An enriched nutritive value and a prolonged shelf life of the baked biscuit product were observed. This could be due to the bioactive antioxidants existed in kohlrabi.

Antioxidant Activity

Kohlrabi leaves generally showed higher antiradical activity in terms of DPPH quenching (ranging from 62.5 to 134.6 mmol ascorbic acid/100 g dw) compared to skins and stems, with the exception of cv. CR22 that was the highest in stems 18.4 mmol ascorbic acid/100 g dw) (Fig. Branca et al. 2013). In contrast, leaves and skins had a similar peroxyl radical (ROO.) scavenging capacity, presumably influenced by the presence of anthocyanins, as suggested by the high correlation between peroxyl radical scavenging capacity and total anthocyanin content ($R^2 = 0.81$). As expected, a significant correlation was found between DPPH quenching and ascorbic acid content and between peroxyl radical and total carotenoids. Interestingly, an unexpected correlation was found between glucosinolate and DPPH determinations and may be related to very high content of glucoerucin.

Antidiabetic Activity

Administration of the aqueous extract of kohlrabi stem to alloxan-induced diabetic rats significantly lowered the blood glucose compared to pretreatment level (Srinivas and Patil 1993). In another study, hyperglycaemic animals showed significant decrease in the blood glucose level after 60 days of treatment with Knol-Khol extract and pioglitazone, compared to streptozotocin-induced diabetic control rats (Rasal et al. 2006). The concentration of malondialdehyde (MDA) was significantly decreased in the Knol-Khol extract and pioglitazone-treated groups. The glutathione content and levels of antioxidant enzymes superoxide dismutase, catalase and glutathione peroxidase were significantly increased in the Knol-Khol extract and pioglitazone-treated groups as compared to diabetic control rats. Sections of the pancreas from the Knol-Khol extract treated diabetic rats showed a good number of regenerating tiny islets, compared to a reduced number of islets in diabetic rats. It was concluded that the petroleum ether extract of Knol-Khol regenerated the pancreas and lowered hyperglycaemia and oxidative stress.

Anticancer Activity

Kohlrabi contained more glucoraphanin, an anticancer compound, than the radish (Choi et al. 2010). Numerous studies in chemically induced models of cancer had found sulforaphane and other isothiocyanates to be potent anticancer (Hecht 2000; Kuroiwa et al. 2006; Razis and Noor 2013).

The major mechanism of inhibition of carcinogenesis by isothiocyanates appeared to be a selective inhibition of cytochrome P450 enzymes involved in carcinogen metabolic activation (Hecht 2000). Isothiocyanates also induced phase II enzymes and enhanced apoptosis, and these properties may also be involved in their chemopreventive activity. Phenethyl isothiocyanate, a particularly effective inhibitor of lung tumour induction by the tobacco-specific nitrosamine 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone, was being developed as a chemopreventive agent against lung cancer. In-vitro studies in Hep G2 cells found that sulforaphane, the breakdown product of glucoraphanin, was more superior than its precursor in modulating various phase I and phase II enzymes involved in carcinogen-metabolising enzyme systems (Razis and Noor 2013). Animal studies by Kuroiwa et al. (2006) suggested that diet supplementation with naturally occurring ITCs like benzyl isothiocyanate and sulforaphane could block N-nitrosobis(2-oxopropyl)amine (BOP) initiation of hamster pancreatic carcinogenesis.

A 12-week dietary intervention study with high-glucoraphanin (HG) broccoli found that the metabolic changes observed with the HG broccoli diet were consistent with a rebalancing of anaplerotic and cataplerotic reactions and enhanced integration of fatty acid β-oxidation with TCA cycle activity (Armah et al. 2013). It was concluded that these modifications may contribute to the reduction in cancer risk associated with diets that are rich in cruciferous vegetables.

Antimutagenic Activity

Except for Chinese cabbage, all cruciferous vegetables including kohlrabi were found to have strong to moderate antimutagenic activities induced by 2-amino-3-methyl[4,5-f]-quinoline (IQ) and in part by 2-amino-3,4-dimethylimidazo[4,5-f]quinoline (MeIQ) or 2-amino-3,8-dimethylimidazo[4,5-f]quinoxaline (MeIQx) in *Salmonella typhimurium* TA98 and TA100 (Edenharder et al. 1994).

Trypsin Inhibitory Activity

A trypsin inhibitor with a Km of 5×10^{-5} M was isolated from kohlrabi (Svendsen et al. 1989). It weakly inhibited subtilisin DY and not chymotrypsin. The inhibitor was closely related to napin as determined by amino acid sequence analysis which also showed the inhibitor to be polymorphous.

Pharmacokinetic Studies

The production of allyl isothiocyanate from sinigrin was investigated in a dynamic in-vitro large intestinal model, after inoculation with a complex microflora of human origin (Krul et al. 2002). Peak levels of allyl isothiocyanate were observed between 9 and 12 hours after the addition of sinigrin. Between 10 and 30 % (mean 19 %) of the sinigrin was converted into allyl isothiocyanate.

Other Uses

As stock feed, kohlrabi can be grazed by ruminants. The young plants are tender and palatable, but the older plants can be tough (Fuller 2004).

Studies indicated that kohlrabi peel was an attractive biomaterial for removing cationic dyes from the dye wastewater (Gong et al. 2007).

Crude extract of kohlrabi was found to be a rich source of peroxidase (POx) (Manzoori et al. 2006). POx catalysed the hydrogen peroxide oxidation of homovanillic acid to produce a dimer which showed strong fluorescence at 420 nm with excitation at 312 nm. This spectrofluorometric method was successfully applied to the determination of hydrogen peroxide in honey.

Comments

A case of methaemoglobinaemia in an infant following nitrite poisoning after a dinner of kohlrabi was reported by Ritter and Schulze (1971). Methaemoglobinaemia is a disorder characterised by the presence of a higher than normal level of methaemoglobin (ferric [Fe^{3+}] rather than ferrous [Fe^{2+}] haemoglobin) in red blood cells. This results in a decreased availability of oxygen to the tissues.

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Brassica rapa var. *rapa*

Scientific Name

Brassica rapa* var. *rapa

Synonyms

Barbarea derchiensis S.S. Ying, *Brassica campestris* var. *campestris*, *Brassica campestris* subsp. *rapa* (L.) Hook. f., *Brassica campestris* subsp. *rapifera* (Metzg.) Sinskaya, *Brassica cibaria* Dierb., *Brassica rapa* var. *quadrivalvis* (Hook. f. and Thomson) Kitam., *Brassica rapa* var. *rapa*, *Brassica rapoasiatica* Sinskaya, *Brassica rapoeuropea* Sinskaya, *Napus rapa* (L.) Schimp. and Spenn., *Raphanus rapa* (L.) Crantz, *Sinapis rapa* (L.) Brot., *Sinapis tuberosa* Poir.

Family

Brassicaceae

Common/English Names

Fodder Turnip, Italian Kale, Rapini, Seven Top Turnip, Stubble Turnip, Turnip, White Turnip

Vernacular Names

Afghanistan: Shalgham
Chinese: Man Jing, Wu Jing, Yuan Bian Zhong
Czech: Brukev Řepák Vodnice, Brukev Vodnice
Danish: Høstroe, Majroe
Dutch: Meiraap, Raap, Stopelknol
Estonian: Naeris
Finnish: Nauris, Turnipsi
French: Navet, Navet Commun, Navet Potager
German: Herbstrübe, Mairübe, Mairüben, Rübe, Saatrübe, Speiserübe, Stoppelrübe, Wasserrübe Weiße Rübe, Weisse-Rübe
Greek: Gogguli, Goggulia
India: Salgam (Hindi)
Italian: Rapa, Napo
Japanese: Dai Kabu, Kabu, Kabura, Ko Kabu, Mini Kabu
Norwegian: Vanleg Nepe
Pakistan: Ginglu, Shaljam
Polish: Kapusta Wlasciwa, Rzepa Jadalna, Rzepa Wlasciwa Typowa, Rzepa Wlasciwa
Portuguese: Nabo, Rábano
Russian: Repa, Turneps
Slovaščina: Strniščna Repa, Vrtna Repa
Slovencina: Kapusta Poľná Pravá
Spanish: Nabo Hortelano, Nabo
Swedish: Rofva, Rova

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Thai: Hua Chai Thao Daeng (Bangkok), Phakkat Farang
Welsh: Meipfresychen

Origin/Distribution

Wild *Brassica rapa* subsp. *oleifera* [includes var. *sylvestris*] is regarded as the species from which *B. rapa* var. *rapa* L. (cultivated turnip) and *B. rapa* var. *silvestris* (Lam.) Briggs (turnip rape) originated. It is native throughout Europe, Russia, Central Asia and the Near East (Prakash and Hinata 1980), with Europe proposed as one centre of origin. Turnip has been used as a vegetable for human consumption in Europe since prehistoric times; it was reported as a well-established crop in Roman and Hellenistic times (Undersander et al. 1992). Nowadays it is cultivated nearly all over the world and has also been introduced to tropical countries, where it is grown at higher altitudes.

Agroecology

Turnip is a cool season crop, recording good growth in full sun during relatively low (4.5–16 °C) temperatures, although it has a temperature range of 3.5–27 °C. Temperatures below 10 °C cause bolting. Hot temperatures cause the roots to become woody and bad tasting. It is cold hardy and drought tolerant, thriving best on a moderately deep, highly fertile, friable loamy soil with pH 5.5–6.8. Turnip can be grown in the tropics at the higher and cooler altitudes.

Edible Plant Parts and Uses

Turnip edible parts are consumed as a raw, boiled and/or fermented vegetable (Ryu et al. 2012). Turnip roots are eaten raw, pickled, braised, pureed or used in soups, stews, casseroles, etc. (Facciola 1990). Bread is sometimes made from turnip with added wheat flour. Small turnips (also called baby turnips) are specialty varieties and can be eaten whole, including their leaves. Leaves are eaten as "turnip greens" ("turnip tops" in the United Kingdom), and they resemble mustard greens in flavour. The cooked leaves make an acceptable vegetable, though they are coarser than the related cabbage. Young leaves can also be added in small quantities to salads, they have a slightly hot cabbage-like flavour and some people find them indigestible. Turnips are fermented and used in *Kimchee* in Korea (Wu et al. 2012).

Botany

A biennial herbaceous plant, to 1 m high with a fleshy, purple, red or greenish or white bulbous, napiform or globose, white-fleshed, 5–20 cm diameter, storage organ that protrudes above ground which is developed from the root and stem base tissues (Plates 1, 2 and 3). The main tap root is thin and about 10 cm long. Basal leaves rarely up to 10, obscurely rosulate; lamina lyrately pinnatifid or rarely sinuate-dentate, glabrous and green on slender fleshy petioles, petiole slender. Upper leaves are sessile, subentire, oblong lanceolate and often constricted above the base. Branches originate in the axils of the highest leaves on the stem, and each terminates in an inflorescence. The inflorescence is an elongated raceme, and the flowers are densely clustered at the top with open flowers borne at or above the level of terminal buds and open upward from the base of the raceme. Flowers bisexual, regular,

Plate 1 Napiform turnip with root cut-off

Plate 2 Globose turnip with leaf bases

Plate 3 Turnip minus leaf bases

4-merous; pedicel up to 3 cm long, ascending; sepals 5–8 mm long, spreading, yellow-green; petals obovate, 0.5–1 cm long, clawed, bright yellow; stamens 6; ovary superior, cylindrical, 2-celled, stigma globose. Fruit is a linear silique 4–10 cm by 2–4 mm, with a tapering beak, dehiscent, up to 30 seeded. Seeds are globose, 1–1.5 mm in diameter, finely reticulate and dark brown.

Nutritive/Medicinal Properties

Turnip Root

Analyses carried out in the United States reported raw, turnip root to have the following proximate composition (per 100 g edible portion): water 91.87 g, energy 28 kcal (117 kJ), protein 0.9 g, total lipid 1.10 g, ash 0.70 g, carbohydrates 6.43 g, total dietary fibre 1.8 g, total sugars 3.80 g, Ca 30 mg, Fe 0.30 mg, Mg 11 mg, P 27 mg, K 191 mg, Na 67 mg, Zn 0.27 mg, Cu 0.085 mg, Mn 0.134 mg, Se 0.7 µg, vitamin C 21 mg, thiamine 0.04 mg, riboflavin 0.030 mg, niacin 0.40 mg, pantothenic acid 0.200 mg, vitamin B6 0.090 mg, total folate 15 µg, vitamin E (α-tocopherol) 0.03 mg, vitamin K (phylloquinone) 0.1 µg, total saturated fatty acids 0.011 g, 16:0 (palmitic) 0.010 g, 18:0 (stearic) 0.001 g, total monounsaturated fatty acids 0.006 g, 16:1 undifferentiated (palmitoleic) 0.001 g, 18:1 undifferentiated (oleic) 0.006 g, total polyunsaturated fatty acids 0.053 g, 18:2 undifferentiated (linoleic) 0.012 g, 18:3 undifferentiated (linolenic) 0.040 g, phytosterols 7 mg, tryptophan 0.009 g, threonine 0.025 g, isoleucine 0.036 g, leucine 0.033 g, lysine 0.036 g, methionine 0.011 g, cystine 0.005 g, phenylalanine 0.017 g, tyrosine 0.013 g, valine 0.030 g, arginine 0.024 g, histidine 0.014 g, alanine 0.035 g, aspartic acid 0.063 g, glutamic acid 0.130 g, glycine 0.025 g, proline 0.026 g and serine 0.029 g (USDA, ARS 2014). Linolenic acid (18:3) was the major fatty acid comprising 56.6–58.6 % of the total fatty acids in turnips, followed by linoleic acid (18:2) (13.9–19.1 %), palmitic acid (16:0) (13–15 %), oleic acid (18:1) (7.1–9.1 %), 17:1 (1.4–2.6 %), stearic acid (18:0) (0.8–1.7 %) and palmitoleic acid (16:1) (0.7–1.1 %) (Lepage 1967). Components of neutral lipids identified were sterol, fatty acid, triglyceride, fatty acid methyl ester, sterol glucosides and sterol ester. Sterol ester, sterol and triglyceride were the most important neutral lipids, but traces of mono- and diglycerides, fatty acid and tocopherol were also present. Among the common phospholipids, cardiolipin and phosphatidylglycerol were abundant components, and phosphatidic acid was also found. Other neutral lipid components detected included phosphatidylcholine, phosphatidylethanolamine, phosphatidylionsitol, digalactosyl diglyceride and monogalactosyl diglyceride (Lepage 1967). Palmitic acid was higher in phosphatidylinositol and digalactosyl diglyceride than in the other components. On the other hand, linoleic acid was less in these two components

and linolenic aid was the major fatty acid in all of them. β-sitosterol was the principal sterol followed by campesterol, and stigmasterol was found in traces. Carotenoids detected in turnip included lycopene (41.9 %), γ-carotene (28.3 %), cryptoxanthin 17.5 % and an unidentified fraction (12.3 %) (Lepage 1967).

Shattuck et al. (1991) found that cold-stored turnip roots decreased in both starch and total sugar concentration (sucrose, fructose and glucose) when compared to freshly harvested roots. Greenhouse-grown plants subjected to low temperatures had roots with a similar starch content but with a higher concentration of total sugars than the control. Cold treatments in the greenhouse and storage induced a slight but significant increase in root sucrose concentration. The ascorbic acid concentration of roots was not affected by low temperature. In both the field and greenhouse studies, low temperature did not change the total concentration of the eight major GSs identified in peeled root and peel tissues, but did alter the concentration of specific glucosinolates. Glucosinolate levels of field-grown turnip roots at 0 and 4 weeks cold storage (0 °C) without peel (μmol/g dw) were determined as 2-hydroxy-3-butenyl glucosinolate (4, 48, 6.00 μmol), 3-hydroxy-4-pentenyl glucosinolate (1.92, 1.94 μmol), 5-methylsulfinylpentyl glucosinolate (0.56, 0.73 μmol), 3-butenyl glucosinolate (0.35, 0.36 μmol), 4-hydroxy-3-indoylmethyl glucosinolate (0.36, 0.40 μmol), 4-pentenyl glucosinolate (2.92, 2.51 μmol), 2-phenylethyl glucosinolate (1.93, 1.80 μmol), 1-methoxy-3-indoylmethyl glucosinolate (0.48, 0.45 μmol) and total glucosinolates (13.01, 14.19 μmol/g). Other glucosinolates found in traces included 3-indoylmethyl glucosinolate, 4-methoxy-3-indolylmethyl glucosinolate and an unidentified saturated butylglucosinolate. In *B. rapa* subsp. *rapa*, the main glucosinolate was the aryl glucosinolate gluconasturtiin (44–47 %) with a relatively high level between 23.6 and 35.9 mg/100 g FM (Krumbein et al. 2005). The major volatile constituents of *Brassica rapa* L. subsp. *rapa* tuberous tap root were 2-phenylethyl isothiocyanate (32.6 %), sec-butyl isothiocyanate (25.7 %), 4-pentenyl isothiocyanate (12.8 %), 5-methylthiopentyl isothiocyanate (10.0 %) and 2-hexenal (4.6 %) (Afsharypuor and Tahmasian 2010).

In a study of 82 different varieties of *Brassica rapa* including 18 varieties of turnip, Yang and Quiros (2010) found that all 18 varieties of turnip from Japan and Wellesbourne, United Kingdom, did not contain the aliphatic glucosinolate, gluconapoleiferin (2-hydroxy-4-pentenyl glucosinolate). The aliphatic glucosinolates found in most of the turnip varieties included progoitrin (2-hyrdoxy-3-butenyl glucosinolate) (12 varieties), sinigrin (2-propenyl glucosinolate) (3 varieties), glucoalyssin (5-methylsulfinylpentyl glucosinolate) (13 varieties), 2-methyl-2-propenyl glucosinolate (6 varieties), gluconapin (3-butenyl glucosinolate) (17 varieties), glucocochlearin (*n*-butyl glucosinolate) (13 varieties), glucobrassicanapin (4-pentenyl glucosinolate) (18 varieties), glucoerucin (4-methylthiobutyl glucosinolate) (11 varieties); indolic glucosinolates detected included 4-hydroxyglucobrassicin (4-hydroxy-3-indolymethyl glucosinolate) (18 varieties), glucobrassicin (3-indolymethyl glucosinolate) (18 varieties), 4-methoxyglucobrassicin (4-methoxy-3-indolylmethyl glucosinolate) (18 varieties), (18 varieties), neoglucobrassicin (*n*-methoxy-3-indolymethyl glucosinolate); and one aromatic glucosinolate found was gluconasturtiin (2-phenylethyl glucosinolate) (18 varieties). Turnips contained much higher levels of aliphatic glucosinolates than indolic glucosinolates. No glucoraphanin was found in all *B. rapa* accessions. Lee et al. (2013) distinguished 4 clusters of 48 turnip accessions from different geographical origins based on 11 different intact and desulfo glucosinolates in the turnip tubers.

Studies showed that nitrogen and sulfur inputs could affect the glucosinolate levels in turnip roots (Li et al. 2007). Total glucosinolate concentration (mg/100 g root fresh weight) varied widely from 9.7 mg at nitrogen 320 kg/ha combined with sulfur 10 kg/ha supply to 91.6 mg ($N_{160}S_{60}$) at nitrogen 160 kg/ha plus sulfur 60 kg/ha. Individual glucosinolate concentrations were increased with increasing S supply regardless of the N treatment, whereas enhanced N supply (160–320 N ha) at the high S level (60 kg/ha) did not affect total glucosinolate concentration.

Individual glucosinolate biosynthesis concentration of N-containing tryptophan-derived indole glucosinolate was highest with increased N supply, whereas S-containing methionine-derived aromatic and aliphatic glucosinolates decreased with increasing N supply combined at low S level (10–20 kg/ha). Turnip cultivars differed in glucosinolate concentrations with the white turnip cultivar, having the highest gluconapin (3-butenyl glucosinolate) concentrations in root and shoot tissues and the red turnip cultivar having the highest total glucosinolate concentration in root tissues (Justen et al. 2012). Blue, red and yellow photoselective netting did not significantly influence total or individual glucosinolates in root tissues. Netting was only a significant factor for glucobrassicanapin (4-pentenyl glucosinolate) concentration in shoots with no netting treatments, resulting in the highest glucobrassicanapin concentrations. May plantings resulted in 50 % higher total glucosinolate concentrations than August plantings. Planting date × year interactions were significant for total and individual glucosinolate concentrations.

Two new indoles, 2-C-β-D-glucopyranosyl-1-methoxyindole-3-acetonitrile and 6-hydroxy-1-methylindole3-acetonitrile, along with two known indoles caulilexin C and arvelexin, were isolated from turnip roots (Wu et al. 2012). A new benzyl α-D-fructofuranoside, along with six known phenol compounds, benzyl-β-D-glucopyranoside, dihydrosyringin, syringin, triandrin, phillyrin and neoolivil-4-*O*-β-D-glucopyranoside, were isolated from turnip roots (Wu et al. 2013). Five flavonoids were isolated from the roots: licochalcone A, 4,4′-dihydroxy-3′-methoxychalcone, liquiritigenin, liquiritin and isoliquiritin (Jeong et al. 2013).

The amount of wax extracted from the periderm of turnip storage organ was very small – 10.3 mg/kg of chloroform extractable material, equivalent to 49 % weight of chloroform extract or 4 μg/cm^2/surface area (Espelie et al. 1980). The composition of parsnip wax comprised 60 % hydrocarbon, 0.7 % wax ester, 7 % fatty alcohol, 29 % fatty acids and 3 % unknown component. Chain length distribution of the fatty alcohols, fatty acids, ω-hydroxy acids and dicarboxylic acids in the polar fraction of the $CHCl_3$ extract of turnip storage organ were 0.95 %, 3.17 %, 0.47 % and 0.9 % respectively.

Turnip Greens/Aerial Parts

Analyses carried out in the United States reported turnip greens (excluding root crown, tough stems and discarded leaves) to have the following proximate composition (per 100 g edible portion): water 89.67 g, energy 32 kcal (132 kJ), protein 1.50 g, total lipid 0.30 g, ash 1.40 g, carbohydrates 7.13 g, total dietary fibre 3.2 g, total sugars 0.81 g, glucose 0.52 g, fructose 0.29 g, Ca 190 mg, Fe 1.10 mg, Mg 31 mg, P 42 mg, K 296 mg, Na 40 mg, Zn 0.19 mg, Cu 0.350 mg, Mn 0.466 mg, Se 1.2 μg, vitamin C 60 mg, thiamine 0.07 mg, riboflavin 0.10 mg, niacin 0.60 mg, pantothenic acid 0.380 mg, vitamin B6 0.263 mg, total folate 194 μg, vitamin A 579 μg RAE, vitamin A 11,587 IU, β-carotene 6,952 μg, lutein + zeaxanthin 12,825 μg, vitamin E (α-tocopherol) 2.86 mg, γ-tocopherol 0.16 mg, vitamin K (phylloquinone) 251 μg, total saturated fatty acids 0.070 g, 10:0 (capric) 0.002 g, 12:0 (lauric) 0.002 g, 14:0 (myristic) 0.003 g, 16:0 (palmitic) 0.054 g, 18:0 (stearic) 0.010 g, total monounsaturated fatty acids 0.020 g, 16:1 undifferentiated (palmitoleic) 0.014 g, 18:1 undifferentiated (oleic) 0.005 g, total polyunsaturated fatty acids 0.120 g, 18:2 undifferentiated (linoleic) 0.036 g, 18:3 undifferentiated (linolenic) 0.084 g, phytosterols 12 mg, tryptophan 0.026 g, threonine 0.082 g, isoleucine 0.078 g, leucine 0.137 g, lysine 0.098 g, methionine 0.034 g, cysteine 0.017 g, phenylalanine 0.092 g, tyrosine 0.058 g, valine 0.102 g, arginine 0.094 g, histidine 0.036 g, alanine 0.103 g, aspartic acid 0.158 g, glutamic acid 0.204 g, glycine 0.090 g, proline 0.071 g and serine 0.061 g (USDA, ARS 2014).

The average dry weight of the edible parts, flower buds, leaves and stems in the medium or late vegetable turnip rape types, was twofold higher (3.20 g) than that of the early types (1.61 g) (Kim et al. 2003). The relative proportion of each edible part to the dry weight in the

early types was approximately 31, 35 and 35 % for the flower buds, leaves and stems, respectively. Two glucosinolate compounds, gluconapin and glucobrassicanapin, were mainly found in all the edible parts. The relative proportion of gluconapin to the total glucosinolate content was higher than that of glucobrassicanapin in the early types, but the reverse was observed in the medium or late types. The total glucosinolate content of edible parts ranged from 60 to 80 mmol/kg DW in all the cultivars, except for "Syunrai" (30 mmol/kg DW) and "No. 88" (31 mmol/kg DW). The phenolic compounds and organic acids of turnip (*Brassica rapa* var. *rapa*) edible parts (leaves and stems, flower buds and roots) were found to compose of 14 phenolics, 3-*p*-coumaroylquinic, caffeic, ferulic and sinapic acids, kaempferol 3-*O*-sophoroside-7-*O*-glucoside, kaempferol 3-*O*-sophoroside-7-*O*-sophoroside, kaempferol 3-*O*-(feruloyl/caffeoyl)-sophoroside-7-*O*-glucoside, kaempferol 3,7-*O*-diglucoside, isorhamnetin 3,7-*O*-diglucoside, kaempferol 3-*O*-sophoroside, 1,2-disinapoylgentiobiose, 1,2′-disinapoyl-2-feruloylgentiobiose, kaempferol 3-*O*-glucoside and isorhamnetin 3-*O*-glucoside, and six organic acids, aconitic, citric, ketoglutaric, malic, shikimic and fumaric acids (Fernandes et al. 2007). The major phenolics were kaempferol 3-*O*-sophoroside-7-*O*-glucoside, kaempferol 3-*O*-(feruloyl/caffeoyl)-sophoroside-7-*O*-glucoside, isorhamnetin 3,7-*O*-diglucoside and isorhamnetin 3-*O*-glucoside as the main phenolics, and malic acid was the organic acid present in highest amounts.

The major isothiocyanate found in turnip were β-phenylethyl isothiocyanate (37,381 μmol/100 g dw followed by 4-pentenyl isothiocyanate (5,357 μmol/100 g dw) and 3-butenyl isothiocyanate (1,858 μmol/100 g dw) (Hong and Kim 2008). The amounts of 3-butenyl and 4-pentenyl isothiocyanates in turnip leaf were higher than those in other parts. β-phenylethyl isothiocyanate, abundant in the root peel, showed the highest content in turnip.

Glucosinolates found in turnip greens included aliphatic glucosinolates, glucoiberin (3-methylsulfinylpropyl glucosinolate), progoitrin (2-hydroxy-3-butenyl glucosinolate), glucoalysiin (5-methylsulfinylpentyl glucosinolate), glucoraphanin (4-methylsulfinylbutyl glucosinolate), gluconapin (3-butenyl glucosinolate), glucobrassicanapin (4-pentenyl glucosinolate), glucoiberverin (3-methylthiopropyl glucosinolate), gluconapoleiferin (2-hydroxy-4-pentenyl glucosinolate), glucobrassicin (3-indolylmethyl glucosinolate), neoglucobrassicin (1-methoxy-3-indolylmethyl glucosinolate) and 4-hydroxyglucobrassicin (4-hydroxy-3-indolylmethyl glucosinolate), and aromatic glucosinolate, gluconasturtiin (2-phenylethyl glucosinolate) (Padilla et al. 2007; Cartea and Velasco 2008). Sixteen glucosinolates identified in 113 varieties of turnip greens from northwestern Spain included aliphatic glucosinolates, glucoiberin (3-methylsulfinylpropyl glucosinolate), progoitrin (2-hydroxy-3-butenyl glucosinolate), glucoalysiin (5-methylsulfinylpentyl glucosinolate), glucoraphanin (4-methylsulfinylbutyl glucosinolate), gluconapin (3-butenyl glucosinolate), glucobrassicanapin (4-pentenyl glucosinolate), glucoiberverin (3-methylthiopropyl glucosinolate), gluconapoleiferin (2-hydroxy-4-pentenyl glucosinolate), glucobrassicin (3-indolylmethyl glucosinolate), neoglucobrassicin (1-methoxy-3-indolylmethyl glucosinolate) and 4-hydroxyglucobrassicin (4-hydroxy-3-indolylmethyl glucosinolate), and aromatic glucosinolate, gluconasturtiin (2-phenylethyl glucosinolate) (Padilla et al. 2007). The aliphatic glucosinolates, gluconapin and glucobrassicanapin, were the most abundant. Other aliphatic glucosinolates, such as progoitrin, glucoalyssin and gluconapoleiferin were relatively abundant in varieties with a different glucosinolate profile. Indolic and aromatic glucosinolate concentrations were low and showed few differences among varieties. Differences in total glucosinolate content, glucosinolate profile and bitterness were found among varieties, with a total glucosinolate content ranging from 11.8 to 74.0 μmol/g dw at one site and from 7.5 to 56.9 μmol/g dw at the other site. Sensory analysis comparing bitterness with variation in glucosinolate, gluconapin and glucobrassicanapin concentrations suggested that these compounds and their breakdown products

and other phytochemicals were probably involved in the characteristic bitter flavour. Turnip greens were reported to be characterised by a sulfurous aroma, pungent flavour and a bitter taste due to isothiocyanates, degradation products of glucosinolates; the intensity of mustard oil/mustard green aroma and flavour and bitterness was significantly affected by variety (Jones and Sanders 2002). Mustard oil/mustard green aroma and flavour, bitterness and bitter aftertaste increased significantly with maturity. Glucosinolates found in turnip tops included aliphatic glucosinolates, glucoiberin (3-methylsulfinylpropyl glucosinolate), progoitrin (2-hydroxy-3-butenyl glucosinolate), gluconapin (3-butenyl glucosinolate), glucobrassicanapin (4-pentenyl glucosinolate), glucoiberverin (3-methylthiopropyl glucosinolate), glucobrassicin (3-indolylmethyl glucosinolate), neoglucobrassicin (1-methoxy-3-indolylmethyl glucosinolate) and 4-hydroxyglucobrassicin (4-hydroxy-3-indolylmethyl glucosinolate), and aromatic glucosinolate, gluconasturtiin (2-phenylethyl glucosinolate) (Rosa 1997; Cartea and Velasco 2008). The major glusinolates were gluconapin (3-butenyl glucosinolate), glucobrassicanapin (4-pentenyl glucosinolate) and gluconasturtiin (2-phenylethyl glucosinolate). Flavonoids isorhamnetin, kaempferol and quercetin glycosides and hydroxycinnamic derivatives were identified in turnip tops (Romani et al. 2006).

Twelve intact glucosinolates, belonging to the three chemical classes, and more than 30 phenolic compounds were found in *B. rapa* leaves and young shoots (turnip greens and turnip tops) (Francisco et al. 2009a). The main naturally occurring phenolic compounds identified were flavonoids and derivatives of hydroxycinnamic acids. The majority of the flavonoids were kaempferol, quercetin and isorhamnetin glycosylated and acylated with different hydroxycinnamic acids. Significant differences for most of compounds were found between plant organs. Total glucosinolate content value was 26.84 μmol/g dw for turnip greens and 29.11 μmol/g dw for turnip tops; gluconapin being the predominant glucosinolate (23.2 μmol/g dw). Phenolic compounds were higher in turnip greens 51.71 μmol/g dw than in turnip tops 38.99 μmol/g dw, in which flavonols were always the major compounds. Phenolic compounds found in turnip greens and top were quercetin derivatives including quercetin-3-*O*-sophorotrioside-7-glucoside, quercetin-3,7-di-*O*-glucoside, quercetin-3-*O*-sophoroside, quercetin-7-*O*-glucoside, quercetin-3-*O*-glucoside, quercetin-3-*O*-(caffeoyl)-sophoroside-7-*O*-glucoside, quercetin-3-*O*-(methoxycaffeoyl)-sophoroside-7-*O*-glucoside, quercetin-3-*O*-(feruloyl)-sopho-roside; kaempferol derivatives kaempferol-3-*O*-sophorotrioside-7-*O*-sophoroside, kaempferol-3-*O*-sophoroside-7-*O*-glucoside, kaempferol-3,7-di-*O*-glucoside, kaempferol-3-*O*-sophoroside, kaempferol-7-*O*-glucoside, kaempferol-3-*O*-(caffeoyl)sophoroside-7-*O*-glucoside, kaempferol-3-*O*-(methoxycaffeoyl)sophoroside-7-*O*-glucoside, kaempferol-3-*O*-(sinapoyl)-sophoroside-7-*O*-glucoside, kaempferol-3-*O*-(feruloyl)-sophoroside-7-*O*-glucoside, kaempferol-3-*O*-(*p*-coumaroyl)-sophoroside-7-*O*-glucoside, kaempferol-3-*O*-(methoxycaffeoyl)-sophoroside, kaempferol-3-*O*-(sinapoyl)-sophoroside, kaempferol-3-*O*-(feruloyl)-sophoroside, kaempferol-3-*O*-(*p*-coumaroyl)-sophoroside; isorhamnetin derivatives isorhamnetin -3,7-di-*O*-glucoside, isorhamnetin-3-glucoside; hydrocinnamic acids 3-caffeoyl quinic acid, 3-*p*-coumaroyl quinic acid, sinapylglucoside, ferulic acid, sinapic acid; 1,2-disinapoy-lgentiobiose; 1-sinapoyl-2-feruloylgentiobiose; 1,2,2′-trisinapoylgentiobiose; and 1,2′-disina-poyl-2-feruloylgentiobiose (Francisco et al. 2009a; Fererres et al. 2008; Cartea et al. 2011). In subsequent studies, Francisco et al. (2009b) found total glucosinolate concentration in turnip tops (25.6 μm/g) was higher than in turnip greens (17.6 μm/g), attributable to differences in aliphatic glucosinolates 20.6 μm/g and 12.8 μm/g, respectively. They found that leaf and stalk firmness and resistance to cutting had negative, significant and moderate to high correlations (ranging from $R=-0.58^{*}$ to $R=-0.88^{**}$) with indolic glucosinolate content and with the aromatic glucosinolates. Gluconapin (the major glucosinolate in these crops) showed positive and

significant correlations with aftertaste, moistness, acid and bitter taste. Hydroxycinnamic acids and flavonoids had a weak relationship with the sensory traits evaluated in turnip tops. Flavonoids kaempferol-3-*O*-(caffeoyl) sophoroside-7-*O*-glucoside and quercetin-3-*O*-(caffeoyl)sophoroside-7-*O*-glucoside displayed correlations highest than $R=0.60$ for leaf and stalk firmness (once again negatives) and for taste traits (acid, salty, bitter and aftertaste persistence). The highest coefficient correlation was found between salty taste and quercetin-3-*O*-(caffeoyl)sophoroside-7-*O*-glucoside ($R=0.82$). The highest difference between turnip greens and turnip tops was found in the hydroxycinnamic acids content. Turnip greens had 27 μm/g of hydroxycinnamic acids concentration and turnip tops 19.3 μm/g. Indolic and aromatic glucosinolates appeared to be more related to traits indicative of texture, while all glucosinolate types (indolic, aliphatic and aromatic) appeared to affect considerably flavour traits, mainly bitterness, acid taste and aftertaste. Results of further studies showed that total glucosinolates and phenolics of turnip greens and turnip tops (sprouting shoots) were significantly affected by the cooking procedure and the loss rate varied among individual compounds (Francisco et al. 2010). Steaming better preserved glucosinolates and phenolic compounds. Conventional boiling and high-pressure cooking methods resulted in similar rate of losses of total glucosinolate content (64 %) and total phenolic content (more than 70 %). Degradation among glucosinolate classes, aliphatic or indolic, was similar. The total flavonoids lost in turnip greens were 64 and 67 % for conventional boiling and high pressure, respectively. Vitamin C concentration suffered a drastic loss in the process of sample handling and after cooking. The results also showed high retentions of individual compounds in steaming, and the lowest retentions were obtained in the traditional high-pressure cooking.

The major volatile components of turnip leaf oil were 4-pentenyl isothiocyanate (53.7 %), sec-butyl isothiocyanate (24.3 %) and 3-butenyl isothiocyanate (15.8 %) (Afsharypuor and Tahmasian 2010). The main volatile constituents of the seed were 3-butenyl isothiocyanate (59.7 %), 4-pentenyl isothiocyanate (31.0 %) and sec-butyl isothiocyanate (1.7 %).

Baenas et al. (2014), in their study of the use of bioelicitors to enrich ready-to-eat sprouts in health-promoting glucosinolates, found that phytohormones methyl jasmonate and jasmonic acid, oligosaccharides glucose and sucrose acted as effective elicitors, increasing the total glucosinolate glucobrassicin content of turnip sprouts from 23.4 to 91.0 mg/100 g.

Antioxidant Activity

Ethanol extract of turnip showed potent scavenging effect on DPPH and inhibitory effect on lipid peroxidation (Choi et al. 2006). Of turnip edible parts (leaves and stems, flower buds and roots), the flower buds exhibited the strongest antioxidant capacity in the DPPH radical scavenging assay (Fernandes et al. 2007).

Hepatoprotective Activity

Oral administration of turnip ethanol extract to D-galactosamine-induced experimental liver injured rats significantly reduced the serum AST, ALT and LDH enzyme activities (Choi et al. 2006). Pretreatment of rats with turnip juice protected the animals against CCL_4-induced hepatotoxicity (Rafatullah et al. 2006). The treatment significantly reduced the serum glutamate-oxaloacetate transaminase (GOT), glutamate-pyruvate transaminase (GPT), alkaline phosphatase (ALP) and bilirubin level at a dose of 16 mL/kg body weight. Besides, the juice also replenished the lowered nonprotein sulfhydryl (NP-SH) concentration in the liver tissue after $CC1_4$ treatment. Turnip aqueous extract exhibited anti-hepatofibrogenic in thioacetamide-induced liver fibrogenesis (Li et al. 2010). Turnip extract significantly decreased hepatofibrosis in thioacetamide animals.

In another study, administration of ethanolic turnip root extract to alloxan-induced diabetic rats significantly decreased the levels of serum

biomarkers of hepatic injury (Daryoush et al. 2011). Additionally, the extract decreased lipid peroxidation and elevated the decreased levels of antioxidant enzymes in diabetic rats. Histopathologically, the changes were in agreement with biochemical findings.

Nephroprotective Activity

In-vitro studies showed that pretreatment of LLC-PK_1 cells with ethanol root extract of B. rapa (EBR) prevented cisplatin-induced decreases in cell viability and cellular glutathione content (Kim et al. 2006). In in-vivo studies, pretreatment of EBR 14 days before cisplatin administration in rats lowered blood levels of blood urea nitrogen and creatinine and of urinary lactate dehydrogenase caused by cisplatin. Moreover, EBR prevented the rise of malondialdehyde production and the induction of aldehyde oxidase and xanthine oxidase activities. This extract also restored the decreased activities of glutathione peroxidase (GPx), superoxide dismutase (SOD) and catalase (CAT) caused by cisplatin. The data indicate that the ethanol extract of roots of *Brassica rapa* exhibited a protective effect against cisplatin-induced nephrotoxicity by attenuating oxidative stress.

Pretreatment of rats with turnip root ethanolic extract for 30 days prior to ischemia/reperfusion operation improved renal function and reduced ischemia/reperfusion-induced renal inflammatory and oxidative injury (Mohajeri et al. 2013). The results of this study showed that the extract significantly prevented renal ischemia/reperfusion-induced functional and histological injuries.

Antidiabetic Activity

Studies by Jung et al. (2008) showed that *B. rapa* root ethanol extract may exert an antidiabetic effect in type 2 diabetic mice by enhancing the glucose and lipid metabolism. The extract and rosiglitazone improved the glucose and insulin tolerance and lowered the blood glycosylated haemoglobin, plasma insulin, C-peptide and glucagon levels as well as reversed these hepatic glucose-regulating enzyme activities in db/db mice. The extract also increased the insulin/glucagon ratio and hepatic glycogen content. The extract and rosiglitazone lowered the elevated plasma-free fatty acid and plasma and hepatic cholesterol and triglyceride levels in db/db mice and simultaneously reduced the hepatic phosphatidate phosphohydrolase, 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA reductase), acyl-coA cholesterol acyltransferase (ACAT), β-oxidation and carnitine palmitoyltransferase activities. Further, the extract lowered the hepatic fatty acid synthase activity, hepatic lipid droplets accumulation and adipose tissue weight and size.

Anticancer Activities

Isothiocyanates had been shown to possess anticarcinogenic properties and to induce apoptosis in various cancer cell lines (Huang et al. 1998; Bonnesen et al. 2001; Yang et al. 2002; Hong and Kim 2008). β-phenylethyl isothiocyanate from turnip root inhibited the growth of human-derived hepatoma cell line (HepG2) in a concentration-dependent manner (IC_{50} value of 24.5 μM), as assessed by the MTT [3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide] method (Hong and Kim 2008). Earlier, Huang et al. (1998) reported that phenylethyl isothiocyanate blocks tumor promoter (12-*O*-tetradecanoylphorbol-13-acetate or epidermal growth factor)-induced cell transformation in mouse epidermal JB6 cells via apoptosis. They demonstrated that p53 elevation was required for phenylethyl isothiocyanate-induced apoptosis. Animal studies by Yang et al. (2002) found that activation of MAP kinases, AP-1 transcription factors, p53 phosphorylation and the induction of apoptosis may be involved in the chemopreventive activity of phenylethyl isothiocyanate and benzyl isothiocyanate. The natural indoles 3,3′-diindolylmethane, ascorbigen, indole-3-carbinol and indolo[3,2-b]carbazole, as well as the natural isothiocyanates sulforaphane, benzyl isothiocyanate and phenethyl isothiocyanate, all possessed cancer

chemopreventive properties by both stimulating apoptosis and enhancing intracellular defences against genotoxic agents (Bonnesen et al. 2001).

Antimicrobial Activity

β-phenylethyl isothiocyanate exhibited antimicrobial activity against food-borne pathogens *Vibrio parahaemolyticus*, *Staphylococcus aureus* and *Bacillus cereus* (Hong and Kim 2008). It was most potent against *Vibrio parahaemolyticus* with minimum inhibitory concentration (MIC) of 100 μg/mL.

Analgesic Activity

Animal studies showed that pretreatment of adult male rats with alcoholic *B. rapa* root extract at doses of 100 and 200 mg/kg body weight caused a significant reduction of pain induced by subcutaneous injection of formalin in the acute phase and at 200 mg/kg body weight caused a significant reduction of pain in chronic phase in comparison to the control group (Hosseini et al. 2013).

Traditional Medicinal Uses

A decoction of turnip leaves or stems is used in the treatment of cancer (Duke and Ayensu 1985). Root boiled with lard is used to treat breast cancer; powdered seed is used as folk remedy for cancer and a slave derived from the flowers is used for skin cancer (Duke 1983). Crushed ripe seeds are used as a poultice on burns (Foster and Duke 1998). In Ganghwa Island, Korea, turnip has been used as a diuretic, digestive and curative for jaundice, etc. (Choi et al. 2006).

Other Uses

Turnip root has been a popular livestock fodder and fodder crops for ruminants. Turnip root peelings contain a natural insecticide. The chopped roots can be brewed into a tea with flaked soap; this is then strained before use against aphids, red spider mites and flies.

Comments

B. rapa and *B. campestris* were first described as two distinct species by Linnaeus, with *B. rapa* being the turnip form and *B. campestris* the wild weedy form. Metzger in 1833 concluded that these were the same species and combined the taxa under the name *B. rapa* (Toxeopus et al. 1984). *B. rapa* (A genome, $n = 10$) was categorised into three well-defined groups based on morphological characteristics: (1) the oleiferous or oil-type rape, referred to in Canada as Polish rape or summer turnip rape; (2) the leafy-type *B. rapa*, including the chinensis group (pak-choi, celery mustard), the pekinensis group (Chinese cabbage) and the perviridis group (tendergreen); and (3) the rapiferous-type *B. rapa*, comprising the rapifera group (turnip, rapini) and the ruvo group (turnip broccoli, Italian turnip) (Hortus Third 1976; Prakash and Hinata 1980).

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Eutrema japonicum

Scientific Name

***Eutrema japonicum* (Miquel) Koidzumi**

Synonyms

Alliaria wasabi (Maxim.) Prantl, *Cochlearia wasabi* Siebold (inval.), *Eutrema japonicum* var. *sachalinensis* (Miyabe & T. Miyake) Nemoto, *Eutrema japonicum* f. *terrestris* (Makino) Nemoto, *Eutrema koreanum* (Nakai) K. Hammer, *Eutrema okinosimense* Takenouchi, *Eutrema wasabi* (Sieb.) Maxim., *Eutrema wasabi* var. *sachalinensis* Miyabe & T. Miyake, *Eutrema wasabi* f. *terrestris* Makino, *Lunaria japonica* Miquel, *Wasabia japonica* (Miquel) Matsumura, *Wasabia koreana* Nakai, *Wasabia okinosimense* (Taken.) Hatus, *Wasabia pungens* Matsumura, *Wasabia wasabi* (Siebold) Makino

Family

Brassicaceae

Common/English Names

Cultivated Wasabi, Japanese Horseradish, Wasabi

Vernacular Names

Brazil: Rabanete Japones, Raiz-Forte (Portuguese)
Chinese: Kuai Jing Shan Yu Cai, Shan Yu Cai, Shan Kui
Czech: Wasabi japonská
Danish: Japansk Peberrod
Dutch: Bergstokroos, Wasabi
Esperanto: Vasabio
French: Raifort Du Japon, Raifort Vert
German: Bergstockrose, Japanischer Kren, Japanischer Meerrettich
Hungarian: Vaszabi
Italian: Wasabi
Japanese: *seiyō* wasabi, namida, Wasabi, Wasabi Daikon
Korean: Wasabi
Russian: Vasabi, Iaponskii Khren
Slovaščina: Wasabi
Spanish: Rabanete Japonês, Wasábia
Swedish: Japansk Pepparrot

Origin/Distribution

Wasabi is native to Japan, Korea, Russia (Far East) and North China. It is cultivated in China, Alisan in Taiwan, Dalat highlands in Vietnam, New Zealand and Tasmania in Australia.

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Agroecology

A temperate species, naturalised in wet areas along streams in mountains from near sea level to 2,500 m. The earliest cultivation of wasabi in Japan dates back to the tenth century. It is now widely cultivated for its edible rhizomes, which are the source of the pungent condiment wasabi. In Japan, it is grown in wet upland orchard soils for leaves, petioles and small enlarged stems and in flooded gravel and sand fields along streams or near springs to produce whole plants and large succulent green enlarged stems (Chadwick et al. 1993).

Wasabi thrives in cool, damp conditions and will sometimes grow if left undisturbed in misty mountain stream beds. It generally requires a climate with an air temperature between 8 and 20 °C and prefers high humidity in summer. Since it is quite intolerant of direct sunlight, wasabi is typically grown under shade cloth or beneath a natural forest canopy.

Edible Plant Parts and Uses

Rhizome plus the base part of the stem is freshly grated to prepare wasabi – a pungent, hot sweetish, relish that is a highly prized culinary ingredient spice and condiment in elite restaurants and sushi bars and homes in Japan. Traditionally, wasabi has been served with raw fish dishes in Japan, because the active constituents within the plant may have been an antidote for food poisoning by killing microbes. This popular spice is preferred fresh and is prepared tableside, often accompanying raw fish (sashimi), sushi (sashimi with boiled rice cake) and cold buckwheat noodles (soba) in Japanese meals (Hodge 1974; Chadwick et al. 1993). Wasabi is also indispensable for preparing *nigiri-zushi*, a special kind of small kneaded ball combining vinegared rice and fish slices. Outside of Japan, this spice is only available dried in the form of a pale green powder or in form of a green paste. Wasabi goes well with dishes containing different kinds of raw fish. Together with a sprinkle of soy sauce, wasabi paste and water go also very well with *tempura*, deep-fried battered vegetables such as Perilla–Giso and in dishes such as sushimi and soba. Wasabi imparts a unique flavour and heat to foods and can be served as a spice or an herb in a dish or as a condiment on the side. A special pickle is also made from fresh-sliced wasabi rhizomes which are cured in the residue left from fermenting rice wine (*sake*). The leaves, flowers, leafstalks and freshly sliced rhizome are soaked in salt water and then mixed with sake lees to make a popular Japanese pickle called *wasabi-zuke*. The leaves can be dried and used for flavour in foods such as cheese, salad dressings and crackers (Sultana and Savage 2008). Also, wasabi wine and a higher alcohol content wasabi liqueur are being sold in some specialty stores.

Botany

An herb growing up to 20–75 cm high, glabrous or sparsely pilose on the upper parts. The rhizome and basal part of the stem is fleshy, to 3 cm in diameter (Plates 2 and 3). Stem is erect or decumbent, simple. Basal leaves rosulate; petiole usually 10–20 cm long and dilated at the base. The leaf blade is cordate or reniform, usually 6–20 cm wide by 6–18 cm long base cordate, margin dentate, denticulate, shallowly crenate, repand or subentire, apex rounded or obtuse (Plate 1). Middle cauline leaves with petioles 1–6 cm; leaf blade broadly ovate to ovate-cordate,

Plate 1 Wasabi plant

Plate 2 Fresh wasabi root

Plate 3 Preserved wasabi root

1.5–6 × 2–6 cm, palmately veined, base and margin as in basal leaves, apex acute. Inflorescence a lax raceme, bracteate throughout or basally. Pedicels ascending or divaricate, slender, 1–3.5(−5) cm. Sepals oblong, 3–4 × 2–2.5 mm, caducous. Petals white, oblong-spatulate, 6–8(−9) × 2–3 mm. Filaments white, 3.5–5 mm; anthers oblong, 0.6–0.8 mm. Fruit linear, 1–2 cm × 1.5–2 mm, terete, torulose. Seeds 6–8, oblong, plump, 2–3 × 1–1.5 mm.

Nutritive/Medicinal Properties

Analyses carried out in the United States reported raw wasabi roots (excluding 23 % peel) to have the following proximate composition (per 100 g edible portion): water 69.11 g, energy 109 kcal (456 kJ), protein 4.8 g, total lipid 0.63 g, ash 1.92 g, carbohydrates 23.54 g, total dietary fibre 7.8 g, Ca 128 mg, Fe 1.03 mg, Mg 69 mg, P 80 mg, K 568 mg, Na 17 mg, Zn 1.62 mg, Cu 0.155 mg, Mn 0.391 mg, vitamin C 41.9 mg, thiamine 0.131 mg, riboflavin 0.114 mg, niacin 0.743 mg, pantothenic acid 0.203 mg, vitamin B6 0.274 mg, total folate 18 μg, vitamin A 35 IU and β-carotene 21 μg (USDA, ARS 2014).

From the nutrient data, wasabi root is rich in minerals like Ca, Mg, K and P; vitamin C; vitamin A; and protein. It also has thiamine, riboflavin, niacin, pantothenic acid, vitamin B6, total folate and β-carotene. In wasabi hydrolysate, the following ten volatile components were detected: methyl, isopropyl, allyl, sec-butyl, 3-butenyl, 4-pentenyl, 5-hexenyl, hexyl, 6-heptenyl and β-phenylethyl isothiocyanates (Kojima et al. 1973).

The best quality wasabi products were reported to be produced from the rhizomes (stems) although other parts of the plant such as petioles and leaves also possessed some pungency and also used as raw materials (sultana et al. 2000). The characteristic flavour of wasabi emanated from the volatile isothiocyanates (ITCs) evolved from glucosinolates by enzymatic hydrolysis when tissues were macerated. The level of total of 6 ITC ranged from 2,425 to 2,810 mg/kg fresh weight, which was significantly

higher than the values reported in the literature for wasabi grown in Japan (mean 1,659 mg/kg). Allyl isothiocyanate (AITC) was the main ITC, and it contributed between 86 and 92 % of the total ITC measured in the rhizomes.

Ina et al. (1989) isolated three ω-methylthioalkyl isothiocyanates, namely, 6-methylthiohexyl isothiocyanate, 7-methylthioheptyl isothiocyanate and 8-methylthiooctyl isothiocyanate as the fresh characteristic greenish flavour components in wasabi. Volatile ω-methylsulfinylalkyl isothiocyanates (NCS) found in the ether extract of wasabi root, stem and leaf were identified as ally NCS (most abundant), *n*-butyl NCS, 3-butenyl NCS, 4-pentyl NCS, 5-hexyl NCS, 5-methylthiopentyl NCS, 6-methylthiohexyl NCS, 7-methylthioheptyl NCS, 5-methylsulfinylpentyl NCS, 6-methylsulfinylhexyl NCS, 7-methylsulfinylheptyl NCS and fatty acids palmitic acid, linolenic acid and oleic acid (Etoh et al. 1990). The flavour of ω-methylsulfinylalkyl isothiocyanates was also slightly wasabi-like although weaker than that of the ω-methylthioalkyl isothiocyanates isolated earlier. The major sulfur-containing compound in wasabi intact root was found to be sinigrin (1-thio-β-D-glucopyranose 1-N-(sulfoxy)-3-buteneimidate) and related congeners; disrupting the cells by applying local pressure allowed the conversion of the sulfur moieties in sinigrin to isothiocyanates and sulfate in approximately equimolar amounts (Yu et al. 2001). Alpha-tocopherol, ubiquinone-10, linolenoyloleoyl-3-β-galactosylglycerol and 1,2-dipalmitoyl-3-β-galactosylglycerol were isolated from wasabi rhizome (Weil et al. 2005).

Volatile components found in the essential oil of different parts of upland wasabi were 1-penten-3-ol (leaf and rhizome), 3-butenonitrile (leaf, petiole, rhizome, root), isopropyl isothiocyanate (leaf), *trans*-2-hexenal (leaf), *sec*-butyl isothiocyanate (leaf, petiole, rhizome, root), cis-2-penten-1-ol (leaf, petiole, rhizome, root), isobutyl isothiocyanate (leaf, petiole, rhizome, root), 1-hexanol (leaf, petiole, rhizome, root), allyl isothiocyanate (leaf, petiole, rhizome, root), unknown (leaf), *cis*-3-hexen-1-ol (petiole, rhizome), *trans*-2-hexen-1-ol (leaf, petiole, rhizome, root), 3-butenyl isothiocyanate (leaf, petiole, rhizome, root), 4-pentyl isothiocyanate (leaf, petiole, rhizome, root), 5-hexenyl isothiocyanate (petiole, rhizome, root), 6-heptenyl isothiocyanate (petiole, rhizome, root), unknown (leaf), 4-methylthiobutanonitrile (leaf, petiole, root), 3-methylthiopropyl isothiocyanate (leaf, petiole, rhizome, root), 6-methylthiohexanonitrile (leaf, petiole, rhizome, root), 4-methylthiobutyl isothiocyanate (rhizome, root), 7-methylthioheptanonitrile (leaf, petiole, rhizome, root), 5-methylthiopentyl isothiocyanate (leaf, petiole, rhizome, root), 6-methylthiohexyl isothiocyanate (leaf, petiole, rhizome, root) and 7-methylthioheptyl isothiocyanate (leaf, petiole, rhizome, root) (Kumagai et al. 1994).

Rhizome contained a glucoside, sinigrin, which when hydrolysed in the presence of an enzyme produces the pungent taste (Hodge 1974). The most prized and hence the most widely grown is a form with green petioles and large knobby greenish rhizomes having a strong pungency.

Wasabi had been reported to produce phytoalexins methyl 1-methoxyindole-3-carboxylate, wasalexins A and B, with antifungal activity against *Phoma lingam* (*Leptosphaeria maculans*, teleomorph) and *Phoma wasabiae* (Pedras and Sorensen 1998; Pedras et al. 1999).

From fresh wasabi leaves five novel flavonoids, isovitexin derivatives acylated by a *trans*-sinapoyl group at C-7, were isolated together with five known flavonoids, apigenin, luteolin, isoorientin (luteolin 6-*C*-β-D-glucopyranoside), isovitexin (apigenin 6-*C*-β-D-glucopyranoside) and isosaponarin (isovitexin 4′-*O*-β-D-glucopyranoside) (Hosoya et al. 2005). Wasabi leaves were found to contain an antimicrobial, hevein-like protein, designated WjAMP-1 (Kiba et al. 2003).

From methanol wasabi leaf extract, seven phenylpropanoid gentiobiosides, namely, 1-(3″,4″-dihydroxy-5″methoxy)-*O*-*trans*-cinnamoyl-2′-*O*-*trans*-sinapoyl gentiobiose; 1,2′-di-*O*-*trans*-sinapoyl gentiobiose; 1-*O*-*trans*-feruloyl-2′-*O*-*trans*-sinapoyl gentiobiose; 1-*O*-*trans*-caffeoyl-2′-*O*-*trans*-sinapoyl gentiobiose;1,2′-di-(3″,4″-dihydroxy-5″-methoxy)-*O*-*trans*-cinnamoylgentiobiose;1-(3″,4″-dihydroxy-5″-methoxy)-*O*-*trans*-cinnamoyl-2′-*O*-*trans*-feruloyl gentiobiose; and 1-(3″,4″-dihydroxy-

5″methoxy)-*O*-*trans*-cinnamoyl gentiobiose, were isolated along with eight known phenylpropanoids: *trans*-*p*-hydroxycinnamic acid; *trans*-ferulic acid; *trans*-sinapic acid; 3,4-dimethoxy-*trans*-cinnamic acid; *trans*-ferulic acid methyl ester; *trans*-sinapic acid methyl ester; 3,4-dihydroxy-5-methoxy-*trans*-cinnamic acid; and 3,4-dihydroxy-5-methoxy-*trans*-cinnamic acid methyl ester (Hosoya et al. 2008).

Antioxidant Activity

Of the phenylpropanoid glycosides isolated from wasabi leaves, 1-(3″,4″-dihydroxy-5″methoxy)-*O*-*trans*-cinnamoyl-2′-*O*-*trans*-sinapoyl gentiobiose; 1-*O*-*trans*-caffeoyl-2′-*O*-*trans*-sinapoyl gentiobiose; 1,2′-di-(3″,4″-dihydroxy-5″-methoxy)-*O*-*trans*-cinnamoyl gentiobiose; 1-(3″,4″-dihydroxy-5″-methoxy)- *O*-*trans*-cinnamoyl-2′-*O*-*trans*-feruloyl gentiobiose; 3,4-dihydroxy-5-methoxy-*trans*-cinnamic acid; and 3,4-dihydroxy-5-methoxy-*trans*-cinnamic acid methyl ester exhibited good superoxide anion radical scavenging in the electrospin resonance method with IC_{50} values of 28.5, 84.5,17.1, 36.0 and 31.3 μM, respectively, compared with ascorbic acid 140 μM (Hosoya et al. 2008). Lee et al. (2010) found that the aqueous wasabi leaf extracts had strong scavenging activities towards 1,1-diphenyl-2-picryhydrazyl (DPPH) and nitric oxide (NO) free radicals in cell-free systems. The extract also inhibited NO production and the expressions of inducible NO synthase (iNOS) mRNA and enzyme protein in lipopolysaccharide (LPS)-stimulated RAW 264.7 macrophage cells.

Anticancer Activity

Animal studies showed that administration of wasabi to male Wistar rats suppressed glandular stomach carcinogenesis induced by the carcinogen MNNG (N-methyl-N′-nitro-N-nitrosoguanidine) (Tanida et al. 1991). The water extract fraction of wasabi markedly suppressed the growth of MKN-28 human stomach cancer, and the morphology of the cancer cells was altered leading to frequent cell death (Fuke et al. 1994). 6-Methylsulfinylhexyl isothiocyanate was identified in wasabi as one of the suppressing components on the growth of MKN-28 (Ono et al. 1996). In subsequent studies, they found that 4-methylsulfinylhexyl isothiocyanate (4-MITC) (a potent inducer of phase 2 detoxification enzymes from broccoli) and 6-MITC (a potent antiproliferative principal from wasabi), 2-MITC and 8-MITC suppressed the growth of murine tumour cells (Fuke et al. 1997). They were also cytotoxic to mouse peritoneal exudate macrophages which were not proliferating in-vitro and inhibited the production of nitric oxide (a potent radical carcinogen) by peritoneal macrophages. Both 4-MITC and 6-MITC slightly inhibited the induction of mouse skin tumour in a two-stage process of carcinogenesis (initiator, 9,10-dimethyl-1,2-benzanthracene; promoter, 12-*O*-tetradecanoylphorbol-13-acetate), but the effect was not significant. Both compounds, however, significantly inhibited the mutation of the skin resulting from topical applications of the carcinogens. Oral administration of 6-methylsulfinylhexyl isothiocyanate (6-MITC) or a 6-MITC-containing T-wasabi fraction from wasabi root inhibited the macroscopic pulmonary metastasis and growth in a murine B16-BL6 melanoma model (Fuke et al. 2006). The number of metastasised foci per lung in either subcutaneous or intravenous injection was significantly reduced by intake of 6-MITC or a T-wasabi fraction.

6-MITC directly affected the cells in the human cancer cell panel such as breast cancer and melanoma cell lines and inhibited their growth in culture, with EC_{50} of 3.9 μM, which was a sufficiently low dosage for practical use (Nomura et al. 2005). The suppression influenced not only the cell growth but also the survival of these cells. The mean concentration to suppress cells to a 50 % survival was 43.7 μM.

6-Methylsulfinylhexyl isothiocyanate (6-MSITC) from wasabi-induced apoptosis in human monoblastic leukaemia U937 cells and human stomach cancer MKN45 cells (Watanabe et al. 2003). Pretreatment of 6-methylthiohexyl isothiocyanate (6MHITC) isolated from wasabi inhibited the development of lung tumours in mice treated

with 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone(NNK), due to the suppression of tumorigenesis initiation stage (Yano et al. 2000). Hou et al. (2000) found that the cancer chemopreventive effect of 6-methylsulfinylhexyl isothiocyanate (6-MSITC) from wasabi was associated with the induction of the cellular expression of nicotinamide adenine dinucleotide phosphate–quinone oxidoreductase (QR) in murine neptoma Hepa 1c1c7 cell. The induction of transcription of the QR gene by 6-MSITC involved an antioxidant/electrophile-responsive element (ARE/EpRE) activation. In a subsequent study, they found that 6-methylsulfinylhexyl isothiocyanate (6-MSITC) exerted cytoprotective and cancer chemopreventive effects by modulating nuclear factor E2-related factor 2 (Nrf2)/Kelchlike ECH-associating protein 1 (Keap1) system in antioxidant-responsive element (ARE)-mediated nicotinamide adenine dinucleotide phosphate (NADP)–quinone oxidoreductase 1 (NQO1) expression (Hou et al. 2011). Similarly 6-methylthiohexyl isothiocyanate (6-MTITC), another major bioactive ingredient in wasabi, was found to have cytoprotective and cancer chemopreventive effects modulated by the same mechanism (Korenori et al. 2013). The natural wasabi compound 6-MITC and its chemical derivative and 6-methylsulfinylhexyl isothiocyanate (I7557) but not 6-methylsulfinylhexyl isothiocyanate (I7447) inhibited the viability of both pancreatic cancer PANC-1 and BxPC-3 cells in a dose- and time-dependent manner (Chen et al. 2014). Morphological observation showed mitotic arrest and apoptosis in 6-MITC- and I7557-treated cells. These two compounds induced G2/M phase arrest and hypoploid population. Percentages of aldehyde dehydrogenase-positive PANC-1 cells were markedly reduced by 6-MITC and I7557 treatment.

Cyclooxygenase and human tumour cell growth inhibitory extract of wasabi rhizome on purification yielded linolenoyloleoyl-3-β-galactosylglycerol, 1,2-dipalmitoyl-3-β-galactosylglycerol, α-tocopherol and ubiquinone-10 (Weil et al. 2005). At a concentration of 250 μg/mL, linolenoyloleoyl-3-β-galactosylglycerol and 1,2-dipalmitoyl-3-β-galactosylglycerol exhibited 42 and 47 % inhibition of COX-1 enzyme. Alpha-tocopherol and ubiquinone-10 isolated from wasabi rhizomes were inactive. At a concentration of 60 μg/mL, linolenoyloleoyl-3-β-galactosylglycerol inhibited the growth of colon, lung and stomach cancer cells by 28, 17 and 44 %, respectively.

Gastroprotective Activity

Oral administration of wasabi leaf extract of 50 and 200 mg/kg bw/day for 10 days to Mongolian gerbils significantly attenuated the elevated level of 8-oxo-7,8-dihydro-2′-deoxyguanosine (8-oxodG) in the stomach and oxidative DNA damage in peripheral erythrocytes caused by simultaneous loading of *Helicobacter pylori* infection and physical stress (Sekiguchi et al. 2010).

Antimicrobial Activity

The antimicrobial activities of distilled water wasabi root extracts were stronger than those of ethanol extracts and stronger against moulds than bacteria (Shin and Lee 1998). Phytoalexins methyl 1-methoxyindole-3-carboxylate, wasalexins A and B, with antifungal activity against *Phoma lingam* (*Leptosphaeria maculans*, teleomorph) and *Phoma wasabiae* were isolated from wasabi (Pedras and Sorensen 1998; Pedras et al. 1999). Of the four kinds of bacteria, *Vibrio parahaemolyticus* was mostly inhibited by the distilled water wasabi root extracts. Hasegawa et al. (1999) found that growth of *Vibrio parahaemolyticus* was inhibited more in fatty tuna meat suspension with a fat content of 3.0 % than in lean tuna meat suspensions, with a fat content of 0.006 %, by wasabi and allyl isothiocyanate. An ethereal extract from wasabi stems had potent antibacterial activity, and 6-methylsulfinylhexyl isothiocyanate was isolated as the active compound from the extract (Ono et al. 1998). Some homologues of 6-methylsulfinylhexyl isothiocyanate were also active against *Escherichia coli* and *Staphylococcus aureus*.

Shin et al. (2004) reported that wasabi roots, stems and leaves exhibited bactericidal activities against *Helicobacter pylori* strains. The leaves of Korean and Japanese wasabi showed the highest bactericidal activities with the minimum bactericidal concentration of 1.05–1.31 mg of dry weight/mL against three strains of *H. pylori*. The roots showed a slightly lower bactericidal activity with 2.09–4.17 mg of dry weight/mL. The bactericidal activity of leaves was higher than that of roots, although the allyl isothiocyanate level of leaves was lower than that of roots. An antimicrobial protein, designated WjAMP-1, purified from wasabi leaves showed antimicrobial activity against both fungi and bacteria (Kiba et al. 2003). The deduced amino acid sequence of cDNA of WjAMP-1 showed 60 and 70 % identity with a hevein from *Hevea brasiliensis* and a hevein-like protein from *Arabidopsis thaliana*, respectively. However, matured WjAMP-1 lacked the hevein domain and may correspond to the C-terminal domain of hevein. WjAMP-1 may be a useful defence gene to generate resistant plants against fungal and bacterial pathogens.

Antidiabetic Activity

6-(methylsulfinyl)hexyl (6-MSITC) derived from *Wasabia japonica* was found to be a an inhibitor of glycogen synthase kinase-3β (GSK-3β), a ubiquitous serine/threonine kinase involved in the molecular pathogenesis of human diseases such as type 2 diabetes and Alzheimer's disease (Yoshida et al. 2011). The most potent isothiocyanate, 9-methylsulfinylhexyl isothiocyanate (9-MSITC), inhibited glycogen synthase kinase 3 at a Ki value of 10.5 μM and showed ATP competitive inhibition. The structure–activity relationship revealed an inhibitory potency of methylsulfinyl isothiocyanate dependent on the alkyl chain length and the sulfoxide, sulfone and/or the isothiocyanate moiety. Their results indicated that MSITCs, including 6-MSITC, could be good lead compounds as GSK-3β inhibitors. They proposed that 6-MSITC or the food ingredient containing it may be useful functional compounds for the treatment of type 2 diabetes.

Antimutagenic Activity

The antimutagenic activity of distilled water wasabi root extracts from horseradish root was stronger against 3-amino-1,4-dimethyl-5H-pyrido (4,3-beta)indole than 2-amino-3,-8-dimethylimidazo-(4,5-f) quinoxaline in the Ames test with *Salmonella typhimurium* TA 98 (Shin and Lee 1998).

Antihypercholesterolemic Activity

Studies showed that feeding hypercholesterolemic Sprague-Dawley rats with wasabi leaf diet for 4 weeks significantly increased serum HDL cholesterol levels compared with the normal diet hypercholesterolemia rats. In contrast, the serum LDL cholesterol levels and liver xanthine oxidase (XO) activity in wasabi leaf diet groups were significantly decreased (Lee 2008; Lee et al. 2010). There were no differences in body weight gain, food intake and food efficacy ratio.

Antiobesity Activity

Hot water wasabi leaf extract suppressed the increase in glycerol-3-phosphate dehydrogenase (GPDH) activity and triglyceride (TG) accumulation, markers of adipogenesis, in a dose-dependent manner (Ogawa et al. 2010). Wasabi leaf extract significantly reduced the mRNA expression levels of peroxisome proliferator-activated receptor (PPAR) γ and CCAAT/enhancer-binding protein (C/EBP) α, both key adipogenic transcription factors, as subsequently were the mRNA expression levels of their target genes, such as adipocyte fatty acid binding protein 2 (aP2). The protein expression levels of both PPARγ and C/EBPα were also inhibited by wasabi leaf extract. The results suggested that wasabi leaf extract may prevent obesity and insulin resistance by inhibiting the differentiation of preadipocytes. Yamasaki et al. (2013) demonstrated that wasabi leaf extract dietary supplement induced mild suppression of obesity in a high-fat diet-induced mice, possibly due to

suppression of lipid accumulation in the liver and white adipose tissue. In epididymal white adipose tissue of the wasabi leaf extract group, expression of leptin, PPARγ and C/EBPα was significantly suppressed and adiponectin was significantly enhanced. Acox, related to fatty acid oxidisation in adipocytes, was also enhanced.

Anti-inflammatory Activity

6-(Methylsulfinyl)hexyl isothiocyanate (6-MITC) attenuated cyclooxygenase-2 (COX-2) production in lipopolysaccharide (LPS)-activated murine macrophage RAW264 cells in a dose-dependent manner (Uto et al. 2005a). It suppressed the activation of JNK-mediated AP-1 and ERK/p38 kinase-mediated CREB or C/EBPδ. They also found that 6-MITC suppressed inducible nitric oxide synthase expression through the inhibition of Janus kinase 2-mediated JNK pathway in lipopolysaccharide-activated murine macrophages. Chen et al. (2010) determined the array of anti-inflammatory genes targeted by 6-MSITC in macrophages. Among 22,050 oligonucleotides, the expression levels of 406 genes were increased by ≥3-fold in lipopolysaccharide (LPS)-activated RAW264 cells, 238 gene signals of which were attenuated by 6-MSITC (≥2-fold). Expression levels of 717 genes were decreased by ≥3-fold in LPS-activated cells, of which 336 gene signals were restored by 6-MSITC (≥2-fold). They suggested that the anti-inflammatory effects of 6-methylsulfinylhexyl isothiocyanate (6-MSITC) may be elucidated by its inhibition of the expression of various proinflammatory genes such as nuclear factor (NF), interleukins IL-1β and IL-6, prostaglandin-endoperoxide synthase 2 (PTGS2) and cyclooxygenase-2 (COX-2) in LPS (lipopolysaccharide)-activated macrophages. On the other hand, 6-MSITC also restored the expression levels of LPS-reduced CC chemokines (CCL11 and CCL25), interleukins (IL-3) and receptors such as interleukin receptor antagonist 12 (IL-1ra12), interleukin 8 receptor alpha (IL-8ra) and tumour necrosis factor receptors (TNFRSF23 and TNFRSF4) to control levels. The data suggested that wasabi 6-MSITC might not only attenuate the expression of certain proinflammatory genes induced by LPS but also restore the expression level of anti-inflammatory genes reduced by LPS. They found that wasabi 6-MSITC regulated the relevant networks of chemokines, interleukins and interferons to exert its anti-inflammatory function.

6-Methylsulfinylhexyl isothiocyanate (6-MSITC) was found to have anti-inflammatory and anticoagulant effects on human umbilical vein endothelial cells (HUVECs) (Okamoto et al. 2014). 6-MSITC modulated endothelial cell function and suppressed cell adhesion. It modulated the generation of activated protein C, essential for negative regulation of blood coagulation, on normal endothelial cells. Also, 6-MSITC reduced tumour necrosis factor-α (TNF-α)-induced interleukin 6 and monocyte chemoattractant protein-1 expression. 6-MSITC markedly attenuated TNF-α-induced adhesion of human monoblastic U937 cells to HUVECs and reduced vascular cell adhesion molecule-1 and E-selectin mRNA expression in activated endothelial cells. This mechanism of the anti-inflammatory effect of 6-MSITC suggested that 6-MSITC may have therapeutic potential as a treatment for vasculitis and vascular inflammation.

Antidiarrhoeal Activity

Studies by Nakayama et al. (1998) found that wasabi extract could inhibit intestinal chloride secretion by inhibiting submucosal secretomotor nerves and prostaglandin synthesis in guinea pig colon and may therefore have an antidiarrhoeal effect. Wasabi extract on the serosal side of the colon reduced basal short-circuit current. The extract reduced the increases in short-circuit current caused by serotonin added to the serosal side and by electrical field stimulation as well.

Collagen Synthesis Enhancing Activity

The results of studies by Nagai et al. (2010) suggested that isosaponarin, from wasabi leaf,

increased type I collagen synthesis in human fibroblasts, by increasing TGF-beta type II receptor (TbetaR-II) protein and TbetaR-II mRNA and prolyl 4-hydroxylase (P4H) protein and P4H mRNA production.

Antiplatelet Activity

Inhibition of platelet aggregation was found in the essential oils extracted from the various parts of upland wasabi (Kumagai et al. 1994). The antiplatelet activity in descending order was highest in roots (IC_{50} = 112.1 μg/mL), petioles (IC_{50} = 125.7 μg/mL) and rhizomes (IC_{50} = 157.3 μg/mL) and lowest in leaves (IC_{50} = 265.6 μg/mL). Most of the volatile components in upland wasabi oils were ω-alkenyl isothiocyanates and ω-methylthioalkyl isothiocyanates, allyl isothiocyanate being the main component in every oil. Essential oils from roots and petioles contained rather large amounts of ω-methylthioalkyl isothiocyanates. Although every authentic isothiocyanate inhibited platelet aggregation, ω-methylthioalkyl isothiocyanates were more inhibitory, which explained the stronger inhibitory effects of essential oils from roots and petioles on platelet aggregation. 6-Methylsulfinylhexyl isothiocyanate (6-MSITC) isolated from wasabi was found to be a potential inhibitor of human platelet aggregation in-vitro (Morimitsu et al. 2000a, b). 6-MSITC administered to rats or mice also showed both activities in-vivo.

Anti-allergic Activity

Various isothiocyanates (ITC) from wasabi were found to inhibit type I allergies by inhibiting chemical mediator release and that the inhibitory effects on each chemical mediator were due to differences in the side chain structure of the wasabi ITCs (Yamada-Kato et al. 2012). Allyl ITC, *sec*-butyl ITC and 3-butenyl ITC, with 3 or 4 carbon chains, inhibited histamine release but did not inhibit the release of leukotriene B4 (LTB4) or cysteinyl LTs (CysLTs). 4-Pentenyl ITC and 5-hexenyl ITC, with 5 or 6 carbon chains and an unsaturated bond at the end, inhibited LTB4 release but did not inhibit the release of histamine or CysLTs. 6-Methylthiohexyl ITC, 6-methylsulfinylhexyl ITC and 6-methyl-sulfonylhexyl ITC, with a sulfur atom inserted at the end of a 6-carbon chain, inhibited the release of histamine, LTB4 and CysLTs and the elevation in intracellular Ca^{2+}.

Bone Stimulatory Activity

Suzuki and Yamaguchi (1999a) demonstrated that wasabi leafstalk extract had an anabolic effect on bone metabolism in rats in-vivo. The extract caused a significant increase in alkaline phosphatase activity, deoxyribonucleic acid (DNA) and calcium contents in the femoral–metaphyseal tissues. They also showed that wasabi leafstalk extract had a stimulatory effect on bone calcification in mouse calvaria tissue culture in-vitro (Suzuki et al. 1997; Suzuki and Yamaguchi 1999b). The extract had an appreciable effect on increasing bone calcium content; the effect was greater at 10 and 50 μg/mL, but at higher concentrations (100–300 μg/mL) the effect was weaker. The bone deoxyribonucleic acid (DNA) content was not significantly altered by the presence of wasabi leafstalk extract (10 and 50 μg/mL). The presence of wasabi leafstalk extract (50 μg/mL) caused a significant increase in calcium content, alkaline phosphatase activity and deoxyribonucleic acid (DNA) content in the diaphyseal and metaphyseal tissues in-vitro (Yamaguchi et al. 2003). However, the effect of wasabi leafstalk extract (50 μg/mL) in increasing bone components was completely abolished in the presence of cycloheximide (10–6 M), an inhibitor of protein synthesis. The results suggested the intake of wasabi leafstalk extract may have a preventive effect on bone loss with increasing age. Wasabi leafstalk extract exerted an enhancing effect on the anabolic action of 17β-oestradiol or insulin, which regulates bone formation and calcification in-vitro (Suzuki and Yamaguchi 2003). The active substance in wasabi leafstalk extract differed from genistein and

17β-oestradiol and had a comparatively lower molecular weight of 158 (Suzuki and Yamaguchi 2004).

Pain-Related Behaviour Activity

Two wasabi non-pungent ITCs, 6-methylsulfinylhexyl isothiocyanate (6-MSITC) and 6-methylsulfinylhexyl isothiocyanate (6-MTITC), dose-dependently activated both murine transient receptor potential ankyrin 1(TRPA1) (EC_{50} = 147 μM for 6-MSITC and 30 μM for 6-MTITC) and human TRPA1 (EC_{50} = 39 μM for 6-MSITC and 34 μM for 6-MTITC) and caused pain-related behaviour that was similar to many other TRPA1 agonists (Uchida et al. 2012). Furthermore, this activation occurred through covalent modification as would be expected from their structures, which were similar to ally ITC. 6-MSITC also activated transient receptor potential vanilloid 1 (TRPV1), a capsaicin receptor, but not other transient receptor potential channels expressed in sensory neurons.

Antiviral Activity

Japanese scientists discovered a potent anti-influenza virus activity in summer leaves of Japanese wasabi (Mochida and Ogawa (2008). The extracts of summer leaves exhibited the same anti-influenza virus activity as winter leaves and showed a stronger activity than stems, roots and rhizomes. The ethanol leaf extract inhibited replication of influenza virus strain (AH1N1, A/shimane/48/2002), its subtype (AH3N2, A/shimane/122/2002) and type B strain (B/shimane/2/2002) regardless of the haemagglutinin antigen type indicating that such extracts could be a promising source of a novel anti-influenza virus agent.

Traditional Medicinal Uses

Traditionally, wasabi has been used as a natural herb for deodorisation and detoxification purposes, as well as for its antimicrobial activity (Okada and Mitsuhashi 2002). The wasabi rhizome is a pungent warming herb that is used internally as an antidote to fish poison (Bown 1995).

Other Uses

Isothiocyanates extracted from *Wasabia japonica* can be used to produce antibiotics, fungicides, insecticides, nematicides and as wood preservatives (Brown and Morra 1997). Studies by Sexton et al. (1999) had shown that volatiles released from glucosinolates in the tissues of *Wasabia japonica* were toxic to the blackleg fungus, *Leptosphaeria maculans*, a major threat of oilseed *Brassica* crops like rapeseed and canola. Wasabi had been reported to produce phytoalexins with antifungal activity, methyl 1-methoxyindole-3-carboxylate, wasalexins A and B, against *Phoma lingam* (*Leptosphaeria maculans*, teleomorph) and *Phoma wasabiae* (Pedras and Sorensen 1998; Pedras et al. 1999).

Comments

Wasabi is commonly propagated from tissue culture offshoots and seeds.

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Lepidium meyenii

Scientific Name

***Lepidium meyenii* Walp**.

Synonyms

Lepidium affine Wedd., *Lepidium gelidum* Wedd., *Lepidium marginatum* Griseb., *Lepidium meyenii* var. *affine* (Wedd.) Thell., *Lepidium meyenii* subsp. *gelidum* (Wedd.) Thell., *Lepidium meyenii* subsp. *marginatum* (Griseb.) Thell., *Lepidium orbignyanum* Wedd., *Lepidium peruvianum* G. Chacón de Popovici, *Lepidium weddellii* O.E. Schulz

Family

Brassicaceae

Common/English Names

Andean Ginseng, Maca, Mace, Pepper grass, Pepper weed, Peruvian Ginseng, Peruvian Maca

Vernacular Names

Czech: Řeřicha Meyenova
Dutch: Maca
French: Maca
Peru: Mace
Quechuan: Ayak Chichira, Ayak Wilku, Huto Huto
Spanish: Maca Andina, Maca-Maca, Maino
Swedish: Maca

Origin/Distribution

The species is native to the high Andean region of Peru and Bolivia. It is also cultivated in some parts of Brazil. The plant has been introduced into the United States, Europe and very recently to China where is being cultivated in the Yunnan province.

Maca is an octoploid plant (Quiros et al. 1996). Molecular DNA studies (RAPD) conducted on 29 cultivated accessions of maca (*Lepidium meyenii*) and 27 accessions of wild species of *Lepidiu*m from Ecuador, Peru and Bolivia found that none of three wild species *L. bipinnatifidum*, *L. kalenbornii* and *L. chichicara* was related enough to be considered ancestral to the cultivated *L. meyenii* (Toledo 1998). *L. bipinnatifidum* comprised mostly of tetraploids and a single octoploid accession; *L. kalenbornii* comprised only of tetraploid accessions; and *L. chichicara* consisted of mostly octoploid and a few tetraploid accessions.

Agroecology

Lepidium meyenii grows in a rather restricted ecological zone in the Andes at 11–12 S latitude and at an elevation of 3,800–4,400 m above sea

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level (Tello et al. 1992; Gonzales et al. 2003a; Clément et al. 2010a, b). Maca has one of the highest frost tolerances of any cultivated plant that can be grown at such high altitudes as it is able to grow in the puna where only alpine grasses and bitter potatoes thrive (Bonnier 1986). At these elevations, temperatures of the growing season vary between −2 and 13 °C in monthly mean minimum or maximum, respectively, and maca will survive subzero temperatures down to −10 °C; relative humidity is moderately high, with an average of 70 % (Tello et al. 1992; Clément et al. 2010a, b). However, maca may be grown outside its native habitat, the Andean highlands of Junín, and the suggesting that its range of adaptation is not as narrow as previously thought (Tello et al. 1992). Today, maca is still mainly cultivated in Peru, in the high Andes of Bolivia, and to a small extent also in Brazil (Flores et al. 2003).

In its high and cold native habitat, maca has adapted to relatively poor agricultural soils, the strong, fierce winds and intense sunlight where few other crops can be grown (Johns 1981). The natural soil in the maca production native habitat is acidic, having a pH of 5 or less (Tello et al. 1992). In its native range, maca grows as an annual crop, completing its life cycle in 1 year (Quiros et al. 1996). However, it is generally regarded as a true biennial plant because it has a vegetative cycle that is followed by a reproductive phase in the following season.

Edible Plant Parts and Uses

Maca (tuberous hypocotyl/root) is used as a food both fresh and dry (Leon 1964). Maca is cooked in pachamancas (underground pits lined with hot stones) or stored dried for later consumption (Leon 1964; Ochoa 2001). Dried macas are cooked in water or milk and used to prepare a kind of sweet and aromatic porridge, *mazamorra*. The small macas are preferred, since they are less fibrous. Macas are also placed in sugar cane rum (*aguardiente*), to which they impart a special aroma. The dried roots are eaten after boiling in water or milk and are sometimes mixed with honey and fruit for preparation of juices and addition of sugarcane rum for cocktails and other alcoholic beverages (Johns 1981; Tello et al. 1992). Flour is also prepared from the dried roots for making bread and cookies. Maca is mixed with *chuño* (freeze-dried potatoes), oca, quinoa and soybeans to prepare different dishes and dessert. In Huancayo, Peru, maca jam and pudding are popular, and maca is often made into a sweet, fragrant, fermented drink or weak beer called *chicha de maca* (Ochoa 2001; Muhammad et al. 2005). The tuberous hypocotyls/roots have a tangy, sweet taste and an aroma similar to that of butterscotch. In 2010 a US-based brewery called Andean Brewing Company became the first company to produce and commercialise beer made from Maca under the brand KUKA Beer (Wikipedia 2014). Toasted and ground maca is used to prepare "maca coffee" (Castro de Leon 1990). Many food supplements containing dried powdered maca hypocotyls are available on the world market (Valentová et al. 2006) such as value-added maca products such as pills, capsules, flour, drinks, liquor, tonic and mayonnaise (Li et al. 2001).

Maca leaves are eaten raw or cooked and have a hot cress-like flavour (Popenoe et al. 1989; Ochoa 2001).

Botany

Lepidium meyenii is an annual or biennial, low-growing herbaceous plant, growing 12–20 cm in height (Plates 1 and 2). The aerial part consists of a rosette of 12–20 frilly, basal leaves on short decumbent stems arising from an underground tuberous, fleshy, turnip-shaped organ formed by the fusion of the hypocotyl and main tap root. The hypocotyl/root varies in size from 3 to 5 cm in its broadest diameter with a circumference of about 15 cm and found in many shades and combinations of white, cream, yellow, grey, purple and red (Plate 3). The tap root bears numerous very thin, lateral roots. The basal leaves are roughly elliptical in outline, 5 cm in length, petiolated and bipinnatifid (Plate 2). The central leaves are 3 cm in length and are deeply bipin-

Plate 1 Drawing of maca plant (c) International Potato Centre, Lima, Peru

Plate 2 Maca plant (Frank Van Keirsbilck)

Plate 3 Swollen, fleshy maca hypocotyls – root (*red*, *purple*, *cream*, *yellowish*, *blackish*) (CIP)

natifid. The apical leaves are less divided, and 1–2 cm in length. According to some authorities, the leaves exhibit dimorphism, being larger in the vegetative phase and reduced in the reproductive cycle. Flowers are small, white, inconspicuous on short 5 mm slender pedicels and are arranged in axillary racemes on generative shoots. Flowers have four erect, concave sepals, four small white petals, oval, bicarpellary ovary with a short style and two fertile stamens with well-developed anthers and several staminodes. The fruit is a two-celled dehiscent silique, slightly emarginated at the apex, 3.5–5 mm long by 2.5 mm wide. The seeds are ovoid, 1.5–2 mm across, smooth and reddish.

Nutritive/Medicinal Properties

Hypocotyl/Root Nutrient/ Phytochemicals

The dried hypocotyls of maca were reported to contain approximately 13–16 % protein and to be rich in essential amino acids. Fresh hypocotyls contained 80 % water with high amounts of iron and calcium (Valerio and Gonzalez 2005). The proximate nutrient composition of maca hypocotyl root per 100 g edible portion had been reported as energy 314 cal, water 15.3 g, protein 11.8 g, fat 1.6 g, carbohydrates 66.40 g, ash 5 g, Ca 247 mg, P 183 mg, Fe 14.7 mg, thiamine 0.2 mg, riboflavin 0.35 mg and ascorbic acid 2.5 mg (National Institute of Nutrition, Lima Peru 1993). Maca had been reported to have the following proximate nutrient composition: protein 10.2 %, fat 2.2 %, carbohydrates 59.0 %, fibre 8.5 %, ash 4.9 %, minerals mg/100 g) Fe 16.6 mg, Mn 0.8 mg, Cu 5.9 mg, Zn 3.8 mg, Na 18.7 mg, K 2,050 mg and Ca 150 mg; amino acids mg/g protein, aspartic acid 91.7 mg, glutamic acid 156.5 mg, serine 50.4 mg, histidine 21.9 mg, glycine 68.3 mg, threonine 33.1 mg, cysteine n/d, alanine 63.1 mg, arginine 99.4 mg, tyrosine 30.6 mg, phenylalanine 55.3 mg, valine 79.3 mg, methionine 28 mg, isoleucine 47.4 mg, leucine 92 mg, lysine 54.3 mg, tryptophan n/d, hydroxyproline 26 mg, proline 0.5 mg and sarcosine 0.7 mg; and fatty acids, lauric 0.8 %, 7-tridecenoic 0.3 %, tridecanoic 0.1 %, myristic 1.4 %, 7-pentadecanoic 1.1 %, palmitoleic 2.7 %, palmitic 23.8 %, 9-heptadecanoic 1.8 %, heptadecanoic 1.8 %, linoleic 12.6 %, oleic 11.1 %, stearic 6.7 %, 11-nonadecanoic 1.3 %, nonadeca-

noic 0.4 %, 15-eicosenoic 2.3 %, arachidic 1.6 %, behenic 2.0 %, nervonic 0.4 %, lignoceric 0.4 %, total SFA 40.1 % and total UFA 52.7 % (Dini et al. 1994; Comas et al. 1997; Valerio and Gonzalez 2005). Maca was also found to contain sterols as steryl acetate derivatives: brassicasteryl acetate 9.1 %, ergosteryl acetate 13.6 %, campestryl acetate 27.3 %, ergostadientyl acetate 4.5 % and sitosteryl acetate 45.5 % (Dini et al. 1994).

Dried maca hypocotyl was found to contain 10.4 % water, 10.2 % proteins, 59 % saccharides, 2.2 % lipids, 4.9 % ash and 8.5 % fibre and mg/100 g of Ca 150 mg, Fe 16.6 mg, Cu 5.9 mg, Mn 0.8 mg, Zn 3.8 mg, thiamine 0.28 mg, ascorbate 8 mg and riboflavin 0.65 mg (Valentová and Ulrichová 2003). Dried maca root from Yunnan province was found to contain protein (12.31 %), crude fibre (32.57 %), fat (0.92 %), vitamins C (314.97 mg/kg), Ca (1,818 mg/kg), Fe (81.2 mg/kg), Zn (23.8 mg/kg), K (18.7 mg/kg), P (1,895 mg/kg) and other mineral elements (Du et al. 2010). Fatty acids consisted of linoleic acid (38.64 %), linolenic acid (26.46 %) and palmitic acid (17.73 %). The content of amino acids was 14.04 %. Maca also contained catechins but much lower than in tea (2.5 mg/g vs. 145 mg/g (Sandoval et al. 2002).

A dehydrated maca hypocotyl (tuber) powder was found to contain 11.6 % protein, 1.09 % fat (of which 86.7 % steroids), 9.08 % fibre, 60.0 % carbohydrates (23.4 % sucrose, 1.55 % glucose, 4.56 % oligosaccharides and 30.4 % polysaccharides), 5.0 % ash and 663 kJ/100 g energy value (Valentová et al. 2006). Ash consisted mainly of potassium (16.2 mg/g), sodium (260 mg/kg), zinc (58.4 mg/kg), iron (72.3 mg/kg), copper (5.14 mg/kg) and nickel (0.49 mg/kg). The contents of arsenic, lead, cadmium and nitrates were below the limit set for foodstuffs. Fatty acids and steroids in maca methanol (2.5 mg/g fatty acids and 14.9 mg/g steroids) and aqueous extracts (6.2 mg/g fatty acids and 9.1 mg/g steroids) expressed as percentage of total fatty acids or steroid content were, respectively, as follows: phenyl hydroxyacetic acid (4.1 %, –), 2-oxononadecanoic acid (2.6 %, –), octadecanoic acid (2.2 %, –), nonadecanoic acid (21.8 %, –), palmitic acid (36.8, 44 %), stearic acid (13.0, 23.9 %), oleic acid (7.2, 11.6 %), linoleic (3.6 %, 8.7 %), linolenic acid (5.4, 5.8 %), eicosanoic acid (1.3, 6 %), 3,5-stigmastadiene (1.6, 3.8 %), 3-hydroxy-5-ergostene 19.2, –%), β-sitosterol 69.8, 48.5 %), 3,5-stigmastadien-7-one (6, 2.6 %), homo-β-sitosterol (3.4, 0.8 %), brassicasterol (–, 18.8 %), isomer of brassicasterol (–, 23.1 %) and avenasterol (–, 4.4 %) (Valentová et al. 2006). Corredo (2008) reported the following nutrient composition of maca hypocotyls: protein 8.87–11.60 %, lipid 1.09–2.2 %, carbohydrate 54.60–60 %, fibre 8.23–9.08 %, ash 4.90–5 % and minerals (mg/100 g) Fe 16.1 mg, Mn 0.8 mg, Cu 5.9 mg, Zn 3.8 mg, Na 18.7 mg, K 2,050 mg and Ca 250 mg. The proximate composition analysis of maca showed 6.57 % moisture, 12.83 % crude protein, 1.05 % crude fat, 4.80 % ash and 74.75 % carbohydrate (Kwon et al. 2009).

Maca root starch presented oval and irregular morphology, with granule size between 7.4 and 14.9 μm in length and 5.8 and 9.3 μm in diameter (Rondán-Sanabria and Finardi-Filho 2009). Maca starch contained 0.28 % lipids, 0.2 % fibre and 0.12 % fixed mineral residue, and no protein; the ratio between the amylose and amylopectin contents was 20:80. It exhibited the following features: purity of 87.8 %, solubility at 90 °C was 61.4 %, the swelling power was 119.0 g water/g starch and the water absorption capacity was 45.9 g water/g starch; the gel turbidity rose 44 % during storing time; the gelatinisation temperature was 47.7 °C and the transition enthalpy 6.22 J/g; the maximum viscosity reached 1,260 UB at 46.4 °C, with breakdown, setback and consistence of 850, 440 and –410 UB, respectively. The low gelling temperature and the stability during gel refrigeration could be adequate for foods requiring moderate temperature process, but not for frozen food.

The polysaccharide in the maca filtrate was extracted by water and precipitated with ethanol, and its content was determined to be 2.25 % (Chen et al. 2007). The optimum extraction parameters for maca polysaccharides were as follows: temperature 100 °C, time 2 hours and solid ratio 1 : 40 (Chen et al. 2008). The extraction rate of maca polysaccharides by ultrasonic wave was

74.4 % under the optimum extracting conditions: ratio of solid to liquid 1:20, time 20 minutes, temperature 50 °C and ultrasonic power 200 W (Pu and Wang 2010). Four *Lepidium meyenii* polysaccharides LMP-60, LMP-70, LMP-80 and LMP-90 were obtained from maca aqueous extract by changing the concentration of ethanol in the process of polysaccharide precipitation (Zha et al. 2014). All of the LMPs were composed of rhamnose, arabinose, glucose and galactose and differed in the contents of monosaccharide. Amylase and glucoamylase were found to effectively remove starch in maca polysaccharides.

Maca had been reported to contain secondary metabolites such as macaridine, macaene (unsaturated fatty acids), macamides and maca alkaloid (Zheng et al. 2000). *Lepidium meyenii* tubers were found to contain the benzylated derivative of 1,2-dihydro-*N*-hydroxypyridine, named macaridine, together with the benzylated alkamides (macamides), *N*-benzyl-5-oxo-6*E*,8*E*-octadecadienamide and *N*-benzylhexadecanamide, as well as the acyclic keto acid, 5-oxo-6*E*,8*E*-octadecadienoic acid (Muhammad et al. 2002). Five additional alkamides, namely, *N*-benzyl-9-oxo-12*Z*-octadecenamide; *N*-benzyl-9-oxo-12*Z*,15*Z*-octadecadienamide; *N*-benzyl-13-oxo-9*E*,11*E*-octadecadienamide; *N*-benzyl-15*Z*-tetracosenamide; and N-(m-methoxybenzyl)hexadecanamide were isolated (Zhao et al. 2005). The main macamides in maca tubers were identified as *n*-benzylhexadecanamide, *n*-benzyl-(9*Z*)-octadecenamide, *N*-benzyl-(9*Z*,12*Z*)-octadecadienamide,*N*-benzyl-(9*Z*, 12*Z*, 15*Z*)-octadecatrienamide and *N*-benzyl-octadecanamide (McCollom et al. 2005). The amount of macamides in the dried plant material ranged from 0.0016 to 0.0123 %. Two macamides, *N*-benzyl-5-oxo-6*E*,8*E*-octadecadienamide and *N*-benzylhexadecanamide, were isolated and purified from maca (Lee et al. 2008). The following macamides were found in maca pentane extract: *N*-benzylhexadecanamide 1.75 %; *N*-benzyloctadecanamide 0/16 %; N-benzyl-9*Z*-octadecenamide 0.34 %; N-(3-methoxybenzyl)-9*Z*-octadecanamide 0.14 %; N-benzyl-(9*Z*,12*Z*)-octadecadienamide 1.26 %; *N*-(3-methoxybenzyl)-(9*Z*,12*Z*)- octadecadienamide 0.10 %; *N*-benzyl-(9*Z*, 12*Z*, 15*Z*)-octadecatrienamide 2.13 %; N-(3-methoxybenzyl)-(9*Z*,12*Z*,15*Z*)-octadecatrienamide 0.26 %, *N*-(3-methoxybenzyl-hexadacanamide 0.08 %; *N*-benzyl-(15*Z*)-tetraisocenamide 0.02 %; and the following comprised 93.76 %: *N*-(3-methoxybenzyl)-6-phenylhexanamide; N-(3-methoxybenzyl)-6-phenylheptanamide; *N*-(3-metho xybenzyl)-7-oxo-7-phenylheptanmide; N-(4-florobenzyl)-hexadecanamide; *N*-(4-chlorobenzyl)-hexadecanamide; *N*-benzyl-*5*-oxoctadecanamide; *N*-(4-chlorobenzyl)-5-oxoctadecanamide; *N*-(3-methoxybenzyl)-6-hexa namide; *N*-(3-methoxybenzyl)-6-heptanamide; *N*-(3-methoxybenzyl)-7-oxo-7-phenylheptanamide; *N*-benzyl-5-oxo-6*E*, 8*E*-octadecadienamide and *N*-pyridine-9*Z*-octadecanamide (synthetic derivative). Melnikovova et al. (2012) found that maca hypocotyls grown in the field in the Czech Republic had significantly lower concentration of macamides compared to Peruvian samples, and no macamides were detected in maca grown in the greenhouse. The main macamides identified in the samples were: *N*-benzylhexadecanamide, *N*-benzyl-(9*Z*)-octadecanamide, methoxy-n-benzyl-(9*Z*,12*Z*)-octadecadienamide, *N*-benzyloctaeca namide, *N*-benzyl- (9*Z*,12*Z*,15*Z*)-octadecatrienamide and *N*-benzyl-(9*Z*,12*Z*,15*Z*)-octadecadienamide and methoxy-n-benzyloctadecatrienamide. Macamides *N*-benzylpalmitamide, *N*-benzyloleamide and *N*-(3-methoxybenzyl) palmitamide were isolated from maca pentane extract (Alquraini et al. 2014). Hadju et al. (2014) isolated the following macamides (*N*-alkylamides) from maca roots: *N*-(3-methoxybenzyl)-(9*Z*,12*Z*,15*Z*)-octadecatrienamide, *N*-benzyl-(9*Z*,12*Z*,15*Z*)-octadecatrienamide and *N*-benzyl-(9*Z*,12*Z*)-octadecadienamide.

The macaene and macamide of the purified standardised product, M-01 and M-02, of dried maca tubers were determined by high-performance liquid chromatography and included three new compounds, *N*-benzyl octanamide, *N*-benzyl-16-hydroxy-9-oxo-10*E*,12*E*,14*E*-octadecatrieneamide and *N*-benzyl-9,16-dioxo-10E,12*E*,14*E*-octadecatrieneamide and 17 other analogues of macaene and macamide (Zheng et al. 2000). The product also contained 3.72 %

free fatty acids, which included 0.14 % caprylic acid, 0.13 % capric acid, 0.97 % lauric acid, 0.38 % myristic acid, 0.67 % palmitic acid, 0.92 % palmitoleic acid, 0.17 % stearic acid, 0.21 % oleic acid, 0.69 % linoleic acid and 0.33 % linolenic acid. Other minor constituents were 0.03–0.04 % sterols (campesterol, stigmasterol, β-sitosterol) and 0.10–0.15 % benzyl isothiocyanate.

Putative active constituents of maca extract contained mg/g: linoleic acid (18:2) 35.5 mg, palmitic acid (C16:0) 25.8 mg, oleic acid (C18:1) 18.5 mg, α-linolenic acid (C18:3) 17.2 mg, β-sitosterol 5.7 mg and campesterol 1.4 mg and macamides N-benzylhexadecanamide 5 mg and *N*-benzyl-5-oxo-6*E*,8*E*-octadecadienamide 2.9 mg (Cho et al. 2013).

Benzyl isothiocyanate was the principal isothiocyanate isolated together with small amount of *p*-methoxybenzyl from maca roots (Johns 1981). Two glucosinolates benzyl glucosinolate (glucotropaeolin) and *m*-methoxybenzyl glucosinolate were isolated from the methanol extract of maca tubers (Dini et al. 2002). Bernart (2006) quantified benzyl isothiocyanate released by the hydrolytic action of the thioglucosidase enzyme on the substrate glucotropaeolin, the predominant glucosinolate of maca hypocotyls. The methanol maca root extract was found to contain free sugars and amino acids; glucosinolates, glucotropaeolin and 3-methoxyglucotropaeolin; isothiocyanates benzyl isothiocyanate and 3-methoxybenzylisothiocyanate; and other compounds (uridine, malate, benzoylmalate) and an alkaloid (1*R*,3*S*)-1-methyltetrahydro-β-carboline-3-carboxylic acid, a molecule which is reported to exert many activities on the central nervous system (Piacente et al. 2002). Another alkaloid identified as a benzylated 1,2-dihydro-N-hydroxypyridine derivative named macaridine was isolated (Muhammad et al. 2002). Two imidazole alkaloids (lepidiline A and lepidiline B) were isolated from maca tuber and identified as 1,3-dibenzyl-4,5-dimethylimidazolium chloride (1) and 1,3-dibenzyl-2,4,5-trimethylimidazolium chloride (2), respectively (Cui et al. 2003). Maca was found to contain a mixture of alkaloids known as macaines 1, 2, 3 and 4 (Chac'on de Popovici 1997; Dini et al. 1994). The contents of total alkaloids in purple maca, white maca and yellow maca cultivated in Yunnan were 4.4078, 2.9193 and 2.2241 mg/g, respectively (Gan et al. 2010). The content of total alkaloids in purple maca was the highest and close to the content of total alkaloids in maca grown in Peru. Maca was found to contain 5 % alkaloids using ultrasonic-assisted extraction with ratio of solid-to-liquid 1 : 40, time 30 minutes, temperature 70 °C and ultrasonic power 200 W (Du and Pu 2011). Luo et al. (2011) used a combination of ultrasonic wave and microwave for extraction of maca alkaloids. The best condition was determined as ultrasonic power of 300 W, microwave power of 352 W, time of 1.2 minutes and solution-to-solid ratio of 60 : 1 (mL/g), and the content of alkaloids of maca extracted could reach 0.69 %, which was 8.7 % higher than the Soxhlet extraction method.

The following compounds were used as the main marker compounds for maca and its products: linoleic acid, linolenic acid, macaene and macamides, *N*-benzyl-5-oxo-6*E*, 8*E*-octadecadienamide and *N*-benzylhexadecanamide (Ganzera et al. 2002). Jin et al. (2007a) found that major essential oil components (e.g. phenylacetonitrile, benzaldehyde, 3-methoxyphenylacetonitrile) of maca produced distinct characteristic peaks, and these behaviours could be applied to the identification of maca or maca products in the market. A total of 32 components (totalling 1.72 %) were identified in the essential oil extracted from Xinjiang maca by steam distillation (Jin et al. 2009). The main components were identified as benzyl isothiocyanate and benzyl nitrile. Meng et al. (2013) found differences in major compounds extracted from maca using different extraction methods and solvents. The main compounds of essential oils extracted from maca by petroleum ether leaching were [(1,1-dimethylethoxy)methyl]-benzene (26.00 %), N-(phenylmethyl)-acetamide (23.47 %) and phthalic acid hexyl octyl ester (23.49 %). The main compounds extracted by steam distillation were 1-isocyano-2-methyl-benzene (81.80 %), while those by ether extraction were benzyl nitrile (56.29 %) and methoxy-acetaldehyde (10.35 %). Volatile compounds from maca root and leaf were different from those of the essential oil or other extracts (Zheng

et al. 2013). In the root volatiles, isothiocyanate contents were the highest (27.26 %), especially 4-ethylphenyl isothiocyanate (>20 %), followed by chloro compounds (circa 20 %) and tetrahydro-3-methylfuran (14 %). These three types of chemicals were probably important factors for maca's special odour. In the leaf volatiles, the highest contents (about 30 %) were found in acids and anhydrides. Ester (<5 %) and terpene (<1 %) compounds in the volatiles of root and leaf were different from that found in maca essential oil.

The major glucosinolates found in fresh maca hypocotyls were the aromatic glucosinolates, benzyl glucosinolate (glucotropaeolin) (16.94 μMol/g) and *p*-methoxybenzyl glucosinolate (6.38 μMol/g), and other glucosinolates such as 5-methyl sulfinylpentyl glucosinolate (glucoalyssin) (0.57 μMol/g), *p*-hydroxybenzyl glucosinolate (glucosinalbin) (1.61 μMol/g), *m*-hydroxybenzyl glucosinolate (0.3 μMol/g), pent-4-enyl glucosinolate (glucobrassicanapin) (0.15 μMol/g), indolyl-3-methyl glucosinolate (glucobrassicin) (0.05 μMol/g) and 4-methoxyindolyl-3-methyl glucosinolate (4-methoxyglucobrassicin) (0.2 μMol/g) (Li et al. 2001). Total glucosinolates found in maca hypocotyls were 25.66 μMol/g.

At harvest, six glucosinolates (GLs) were identified: 5-methylsulfinylpentyl, 4-hydroxybenzyl, benzyl, 3-methoxybenzyl, 4-hydroxy-3-indolylmethyl and 4-methoxy-3-indolylmethyl, of which benzyl glucosinolate was the most abundant in the hypocotyls of yellow, red and black maca ecotypes, representing 80 % of the total GLs (Yábar et al. 2011). A significant increase in GLs was observed for the three ecotypes during the 90 days before harvest and during the 15–30 days of postharvest drying. This was followed by an important decrease of GLs during the 30–45-day period, which was attributed to cell breakdown, due to fluctuations in temperatures during the drying process and was correlated with a high myrosinase action. During the last period of postharvest drying, GLs were much lower and correlated to lower myrosinase activity and lower maca hypocotyl humidity. Tu et al. (2011) found that myrosinase in maca could be inactivated completely after 60 seconds microwave treatment at a microwave intensity of 14 W/g and a material/liquid ratio of 2:1 (g/mL). The losses of glucosinolates and vitamin C in maca subjected to microwave treatment revealed a decrease by 28 % and 21 % when compared with conventional hot water blanching. However, no significant difference in protein loss between both treatment methods was observed.

Clément et al. (2010a) found that in maca hypocotyls, the colour type effect was significant for most secondary metabolites; exceptions were β-sitosterol and campesterol. The lead-coloured, yellow and violet maca hypocotyls were rich in glucosinolates, macaene and macamides, respectively. Previous cultivation affected macaene, campesterol and indole glucosinolate concentrations. Effects on metabolite concentrations in the leaves were minor. Hypocotyls were richer in macaene, macamides and glucosinolates than were leaves but were poorer in βa-sitosterol and total phenols. Leaves may be interesting for animal nutrition purposes as they contained essentially the same secondary metabolites as the hypocotyls but in clearly lower concentrations. Zhao et al. (2012) found that planting site was the major determining factor with regard to metabolite variations in maca hypocotyls, while the colour of maca accession appeared to be of minor importance in this respect.

Maca was found to contain (1R,3S)-1-methyl-1,2,3,4-tetrahydro-β-carboline-3-carboxylic acid (MTCA),a biologically active alkaloid (Gonzales and Gonzales-Castañeda 2009). Maca meal was reported to contain flavonoids like quercetin (Lee et al. 2005). Optimal conditions for the ultrasonic-assisted extraction of flavonoids from maca by response surface methodology were an ethanol concentration of 70.3 %, solid-to-liquid of 1:27 and ultrasonic time of 28.4 minutes (Zhou et al. 2012).

Seed Phytochemicals

In maca seeds, the glucosinolates were: 5-methyl sulfinylpentyl glucosinolate (glucoalyssin) (11.18 μMol/g), *p*-hydroxybenzyl glucosinolate

(glucosinalbin) (1.7 μMol/g), *m*-hydroxybenzyl glucosinolate (19.31 μMol/g), benzyl glucosinolate (glucotropaeolin) (29.7 μMol/g) and 4-methoxy-indolyl-3-methyl glucosinolate (4-methoxy-glucobrassicin) (7.56 μMol/g) (Li et al. 2001). Total glucosinolates found in maca seeds were 69.45 μMol/g.

Leaf Phytochemicals

In maca fresh leaves, the glucosinolates were the same as those found in the hypocotyls: 5-methyl sulfinylpentyl glucosinolate (glucoalyssin) (0.09 μMol/g), *p*-hydroxybenzyl glucosinolate (glucosinalbin) (0.25 μMol/g), *m*-hydroxybenzyl glucosinolate (0.2 μMol/g), pent-4-enyl glucosinolate (glucobrassicanapin) (0.1 μMol/g), benzyl glucosinolate (glucotropaeolin) (2.3 μMol/g), indolyl-3-methyl glucosinolate (glucobrassicin) (0.02 μMol/g), *p*-methoxybenzyl glucosinolate (0.66 μMol/g) and 4-methoxyindolyl-3-methyl glucosinolate (4-methoxyglucobrassicin) (0.15 μMol/g) (Li et al. 2001). Total glucosinolates found in maca fresh leaves were 3.7 μMol/g.

Maca leaves and roots were found to contain large quantities of glucosinolates with glucotropaeolin as the main glucosinolate around 20 μmol/g dm in the leaves and up to 195 μmol/g dm in the roots (Marthe et al. 2003). In addition, other glucosinolates were found in leaf and root in smaller amounts: sinalbin, benzyl glucosinolate, 4-hydroxy-glucobrassicine, benzyl glucosinolate and 4-methoxy-glucobrassicine. Glucosinolates X6 and X8 were not identified. Also, small quantities of flavonoids were determined, but not identified.

Fourteen components were identified in yellow maca leaf oil, which represented more than 99 % of the total composition of the oil (Wang and Zhao 2011). The major components of yellow maca leaf oil were: butanol (26.35 %), ethyl acetate (17.10 %) and benzyl isothiocyanate (16.95 %). Other minor constituents were acetaldehyde diethyl acetal (3.04 %), benzyl nitrile (2.88 %), benzyl thiocyanate (2.04 %), tricosane (3.90 %), 4-methoxybenzylisothiocyanate (0.68 %), docosane (0.20 %), tetracosane (2.67 %), pentacosane (6.92 %), heptacosane (10.52 %), octacosane (6.48 %) and nonacosane (0.25 %). The red maca leaf oil was found to contain appreciable amounts of butanol (66.02 %), heptacosane (8.90 %) and pentacosane (7.33 %). Other minor components were ethyl acetate (5.81 %), benzyl isothiocyanate (1.02 %), docosane (0.42 %), tricosane (5.74 %), tetracosane (0.64 %), octacosane (3.81 %) and nonacosane (0.23 %).

Phenyl acetonitrile (85.9 %), benzaldehyde (3.1 %) and 3-methoxyphenylacetonitrile (2.1 %) were the major components of the 53 components steam distilled oil from maca aerial plant (Tellez et al. 2002).

Phytochemicals in Maca Products

The following glucosinolates (μM/g) were found in some products derived from maca (Li et al. 2001): sprout 5-methylsulfinylpentyl glucosinolate (0.73 μM), *p*-hydroxybenzyl glucosinolate (12.64 μM), benzyl glucosinolate (0.2 μM) and *p*-methoxybenzylglucosinolate (4.66 μM); flour 5-methylsulfinylpentyl glucosinolate (0.05 μM), *p*-hydroxybenzyl glucosinolate (0.49 μM), benzyl glucosinolate (2.7 μM) and *p*-methoxybenzylglucosinolate (0.88 μM); capsule 5-methylsulfinylpentyl glucosinolate (0.11 μM), *p*-hydroxybenzyl glucosinolate (0.50 μM), benzyl glucosinolate (3.78 μM), *p*-methoxybenzylglucosinolate (1.35 μM) and 4-methoxyindolyl-3-methyl glucosinolate (1.01 μM); pill 5-methylsulfinylpentyl glucosinolate (0.1 μM), *p*-hydroxybenzyl glucosinolate (0.41 μM), benzyl glucosinolate (2.31 μM) and *p*-methoxybenzylglucosinolate (0.58 μM); and mayonnaise allyl glucosinolate (sinigrin) (2.14 μM), benzyl glucosinolate (0.48 μM), *p*-methoxybenzylglucosinolate (0.07 μM). No glucosinolates were detected in liquor and tonic. β-sitosterol was extracted from the lipid fraction of maca; from 5 g of dry maca flour and 8 g of maca; pill, 0.18 mg and 0.22 mg of β-sitosterol per gram of sample were obtained (Parvina et al. 2009).

Pharmacological Activities

Numerous studies had reported on the effects of maca on sexual function, spermatogenesis, female reproductive function, memory, ageing, depression and anxiety and energy as well as effects on benign prostatic hyperplasia, osteoporosis, metabolic syndrome and safety in consumption (Gonzales et al. 2014). Differences have been shown between the effects of the black, yellow and red maca varieties. Black maca showed the best results on spermatogenesis, memory and fatigue, while red maca is the variety thaws effective in reversing benign prostatic hyperplasia and experimentally induced osteoporosis. In addition, maca reduced the glucose levels, and its consumption was related to the lowering of blood pressure and an improved health score. Maca alkaloids, steroids, glucosinolates, isothiocyanates and macamides were held to be probably responsible for its aptitude to act as a fertility enhancer, aphrodisiac, adaptogen, immunostimulant and anabolic and to influence hormonal balance (Valentová and Ulrichová 2003). Experimental scientific evidence showed maca to have nutritional, energiser and fertility-enhancer properties and to act on sexual dysfunctions as well as increasing sperm count and motility, osteoporosis, benign prostatic hyperplasia, memory and learning and to protect skin against ultraviolet radiation (Gonzales 2012). Randomised clinical trials had shown that maca has favourable effects on energy and mood and may decrease anxiety and improve sexual desire. Maca had also been shown to improve sperm production, sperm motility and semen volume (Gonzales et al. 2009). Maca also exhibited great potential as an adaptogen and appeared to be promising as a nutraceutical in the prevention of several diseases. Muhammad et al. (2005) had published a review on maca providing an analysis of in-vitro and in-vivo biological activity, including clinical studies of various crude extracts from different types of maca for its uses for nutritional, chemoprevention, aphrodisiac and fertility-enhancing purposes.

Antioxidant Activity

The aqueous extract of maca (0.3–1 mg/mL) scavenged peroxynitrite (300 mM) by 15.0 and 41.1 %, respectively (Sandoval et al. 2002). Maca (0.03–3 mg/mL) quenched DPPH (100 mM) in a dose-dependent manner with IC_{50} value for DPPH inhibition was 0.61 mg/mL. Results from the peroxyl assays indicated that maca decreased peroxyl formation, a key step in lipid peroxidation with IC_{50} value for peroxyl was 0.43 mg/mL. The results demonstrated that maca contained water-soluble scavengers that may contribute to decompose peroxyls produced during inflammatory states; hence maca may provide cytoprotective effects. Also, maca (1–3 mg/mL) afforded deoxyribose protection against hydroxyl radicals in the range of 57–74 %, respectively. Maca (1 mg/mL) protected Raw 264.7 macrophages against DNA damage induced by peroxynitrite in which had been shown to induce apoptosis in several cell lines and increased ATP production in cells treated with hydrogen peroxide. The concentrations of catechins in maca was lower than in green tea (2.5 mg vs 14.5 mg/g). The catechins found in maca included: catechin 0.32 mg/g, epicatechin 0.17 mg, epicatechin gallate 0.37 mg, epigallocatechin 0.66 mg and epigallocatechin gallate 0.92 mg. The results indicated that maca had the capacity to scavenge free radicals and to protect cells against oxidative cells. The observed cytoprotective effects of maca may be due in part to its capacity to diminish the deleterious effects of excessive production of reactive oxygen species.

The aqueous and methanol extracts of dehydrated maca hypocotyl exhibited weak DPPH radical scavenging activity with IC_{50} values of 3.46 and 0.71 mg/mL, respectively (Valentová et al. 2006). The extracts did not exhibit cytotoxicity in hepatocyte primary cultures up to 10 mg/mL as measured by the MTT viability test and lactate dehydrogenase (LDH) and aspartate aminotransferase (AST) leakage. Moreover, after 72 hours, the extracts inhibited LDH and AST leakage from the hepatocytes. When hepatocytes

were intoxicated by t-butyl hydroperoxide, neither extract prevented oxidative damage. In contrast, Lee et al. (2005) reported an IC_{50} of 100–500 μg/mL for DPPH scavenging activity.

The extraction yields of maca with water, methanol and ethanol extracts were 46.2 %, 21.4 % and 16.8 %, respectively, while the acetone, ethyl acetate, chloroform and hexane exhibited very low extraction yield, ranging from 0.2 to 1.0 % (Kwon et al. 2009). Total polyphenol contents and the nitrite scavenging ability were the highest in maca water extract. Electron-donating ability and the superoxide dismutase (SOD)-like activity were the highest in the methanol extract. When water extract was drawn out at different extraction temperatures (30, 70, 100 °C) and time (1, 3, 5 hours), the improved biological activities (total polyphenol contents, electron donating ability, SOD-like activity and nitrite scavenging ability) were found in extracts treated at 100 °C for 3 or 5 hours). Maximum yields of 16.4 μmol/g of dried matter (DM), 9.89 mg of gallic acid equivalents (GAE)/g of DM and 61.4 μmol of trolox equivalents (TE)/g were obtained from maca hypocotyls at conditions of 47, 70 and 70 °C; liquid-to-solid ratio of 10, 16 and 10 ml/g; extraction time of 90, 30 and 48 minutes; and ethanol concentration of 60 %, 60 % and 50 %, for glucosinolates (GLs), total phenolic compounds (TPC) and antioxidant capacity (AC), respectively (Campos et al. 2013). Optimal extraction conditions for the simultaneous extraction of GLs, TPC and AC determined by response surface methodology were 70 °C, 10 ml/g, 90 minutes and 58 % ethanol with extraction yields of 14.2 μmol/g of DM, 9.3 mg of GAE/g of DM and 56.9 μmol TE/g for GLs, TPC and AC, respectively. Under these conditions, glucotropaeolin represented 79 % of total GLs, and catechins and gallocatechin derivatives represented 97 % of total phenolics.

Maca polysaccharide exerted weak effect of scavenging superoxide anion O^{-2}, but it exhibited a significant potency in inhibiting murine erythrocyte haemolysis; the maximal rate of inhibition was 76.9 % when its concentration reached 50 μg/mL (Zhang et al. 2005). It also reduced lipid peroxidation; malondialdehyde was remarkably decreased in guinea pig liver homogenate. Pu and Wang (2009) reported maca polysaccharide exhibited marked effect of antioxidation in-vitro. Their studies showed that 80 % alcohol-precipitated polysaccharide of maca had the strongest in-vitro antioxidant activities (DPPH radical, the ability to remove hydroxyl radical and the scavenging activity of superoxide anion radical) while the 60 % alcohol-precipitated polysaccharides had the weakest in-vitro antioxidant activities. Chen et al. (2010) reported that antioxidation before and after carboxymethylation showed maca polysaccharide to be quite effecting in scavenging hydroxyl free radical using the Fe^{2+}–H_2O_2 system. Antioxidant activity tests revealed that of four *Lepidium meyenii* polysaccharides LMP-60, LMP-70, LMP-80 and LMP-90, and LMP-60 showed good capability of scavenging hydroxyl free radical and superoxide radical at 2.0 mg/mL; the scavenging rates were 52.9 % and 85.8 %, respectively (Zha et al. 2014).

Anticancer Activity

Benzyl isothiocyanate had been reported to exert an inhibitory effect on the occurrence of 7,12-dimethylbenz(a)anthracene-induced neoplasia of the breast of Sprague-Dawley rats (Watterberg 1981). Benzyl isothiocyanate was found to have chemopreventive effects against diethylnitrosamine (DEN)-induced hepatocarcinogenesis in rats (Sugie et al. 1993). Maca imidazole alkaloid compounds 1,3-bis (phenylmethyl)-4,5-dimethyl-1H-imidazlium chloride and 1,3-bis(phenylmethyl)-2,4,5-trimethyl-1H-imidazlium chloride exhibited potential to treat proliferative diseases, including cancer (Cui et al. 2005).

Lepidium meyenii (Red Maca) was listed as one of several plants providing some improvements on benign prostatic hyperplasia (Shrivastava and Gupta 2012).

Freeze-dried aqueous extract of red maca, hydroalcoholic extract of red maca and finasteride reduced prostate weight in rats with prostatic hyperplasia induced by testosterone enanthate (Gonzales et al. 2007, 2008). No difference was

observed between the data obtained from aqueous extract or hydroalcoholic extract of red maca. A dose-dependent reduction of prostate weight was observed with the increase of the dose of benzyl glucosinolates in red maca extracts. Testosterone enanthate increased prostatic stromal area, and this effect was prevented by treatment with red maca after 7 days treatment. After 21 days of treatment with red maca, prostate size and weight of prostate hyperplastic mice were reduced. In another study, red maca administered orally in rats appeared to exert an inhibitory effect at a level post-DHT (dihydrotesterone) conversion, on testosterone enanthate-induced benign prostatic hyperplasia (Gasco et al. 2007b). The prostate weight diminished in a dose-dependent fashion in rats treated with red maca, and the effect of red maca was better than that observed with finasteride. Administration of red maca extract from day 1 to day 14 reduced prostate size and zinc levels in rats with prostatic hyperplasia induced by testosterone enanthate (Gonzales et al. 2012).

Fertility Enhancing/Aphrodisiac/ Sexual Dysfunction Ameliorating Activities

Maca is an Andean plant with multipharmacological functions, but most scientific attention had been focused in the areas of enhancement of sexual drive in humans, increasing overall vigour and energy levels and increasing sexual fertility in humans and domestic livestock (Wang et al. 2007). *Lepidium meyenii* had been included in the list of plants with poetical as alternative treatments for female sexual dysfunction (Mazaro-Costa et al. 2010).

In-Vitro Studies

Maca extracts (obtained with different solvents: methanol, ethanol, hexane and chloroform) did not exert direct androgenic activities (Bogani et al. 2006). The extracts were not able to regulate GRE (glucocorticoid response element) activation. They suggested that further studies were needed to elucidate which compound, of the several Maca's components, was responsible for the observed in-vivo effects. Both methanolic and aqueous maca hypocotyl extracts exhibited estrogenic activity comparable with that of silymarin in MCF-7 human breast cell line (Valentova et al. 2006). Maca oestrogenicity was exhibited in the range from 100 to 200 μg of extract per ml. Both extracts did not exhibit cytotoxicity in hepatocyte primary cultures up to 10 mg/mL. Moreover, after 72 hours, both extracts inhibited lactate dehydrogenase and aspartate aminotransferase leakage from the hepatocytes. In contrast, a slight cytoprotective effect, probably not mediated by antioxidant capacity, was noted.

Animal Studies

In-vivo studies in rats by Chacón (1990) and Rea (1992) indicated that feeding female rats with maca extract enhanced fertility probably by stimulating the maturation of the Graaf follicles. In males, maca extract was found to stimulate spermatogenesis (Chacón 1990). Johns (1981) suggested that the fertility-enhancing properties of maca may be due to the presence of biologically active aromatic isothiocyanates derived by hydrolysis of the glucosinolates and specifically due to benzyl isothiocyanate and *p*-methoxybenzyl isothiocyanates. The putative aphrodisiac powers of maca could also be attributed to the presence of prostaglandins and sterols in the hypocotyls (Dini et al. 1994) and to the amides of polyunsaturated fatty acids, which were presumably found to enhance sexual function in rats and mice (Zheng et al. 2000).

Oral administration of a purified lipidic maca extract enhanced the sexual function of mice and rats, as evidenced by an increase in the number of complete intromissions and the number of sperm-positive females in normal mice and a decrease in the latent period of erection in male rats with erectile dysfunction (Zheng et al. 2000). The study suggested an aphrodisiac activity of *L. meyenii* presumably attributable to the presence of amides of polyunsaturated fatty acids in the extract. Studies by Cicero et al. (2001) found both acute and chronic maca oral administration significantly improved sexual performance parameters in male rats. After 15 days of maca

treatment, both doses (15 and 75 mg/kg) were able to significantly decrease first mount, first intromission, ejaculation and post-ejaculatory latencies, while the 75 mg/kg dose decreased the intercopulatory interval too. The chronic maca treatment induced an apparently non dose-related increase in rat locomotion. In further studies, they found oral administration of hexanic, methanolic and chloroformic extracts of maca root significantly decreased intromission latency and intercopulatory interval and increased intromission frequency and copulatory efficacy of sexually inexperienced male rats as compared to controls (Cicero et al. 2002). Hexanic and methanolic extracts were able to increase mount frequency (MF), while only hexanic fraction significantly improved mount latency. Overall, only the hexanic fraction significantly improved the majority of the sexual parameters measured.

Oshima et al. (2003) found that progesterone levels increased significantly in mice that received maca, while testosterone levels increased significantly in mice that received maca as well as in those that received both maca and *Jatropha macrantha*. However, there were no marked changes in blood levels of oestradiol-17beta or the rate of embryo implantation. Oral administration of the ethanol maca extract at 48 mg/day or 96 mg/day activated onset and progression of spermatogenesis in rats (Gonzales et al. 2003b). Gonzales et al. (2004) found that treatment of rats with maca at high altitude prevented high altitude-induced spermatogenic disruption. Exposure to high altitude resulted in a reduction in epididymal sperm count after 7 days, and lower values were maintained up to 21 days. Altitude reduced spermiation (stage VIII) to half and the onset of spermatogenesis (stages IX–XI) to a quarter on days 7 and 14, but treatment with maca (666.6 mg/day) prevented these changes. Data on transillumination and epididymal sperm count in the maca-treated group exposed to high altitude were similar to those obtained at sea level. Furthermore, in the maca-treated group exposed for 21 days to high altitude, epididymal sperm count was higher than in the non-treated group at sea level.

Treatment of male rats with maca resulted in an increase in the weights of testis and epididymis, but not the seminal vesicle weight (Gonzales et al. 2001b). The length and frequency of stages IX–XIV seminiferous tubules, where mitosis occurred, were increased, and stages I–VI were reduced in rats treated with maca. The results indicated that maca invigorated spermatogenesis in male rats by acting on its initial stages. Black maca was found to increase sperm count at epididymal level as early as 1 day after beginning of treatment and to increase in sperm count at the vas deferens of male rats (Gonzales et al. 2006a). Maca treatment enhanced spermatogenesis following spermatogenic damage induced by a single dose of organophosphate insecticide malathion in mice (Bustos-Obregon et al. 2005). Assessment of the relative length of stages of the seminiferous epithelium showed that maca treatment resulted in rapid recovery from the effect of malathion.

Rubio et al. (2006b) reported that maca administration reduced the deleterious effect on daily sperm production of rats caused by lead acetate treatment suggesting that Maca may have potential in the treatment of male infertility associated with lead exposure. Of the maca genotypes, black maca increased daily sperm production and epididymal sperm motility in adult rats (Gonzales et al. 2006b). Red or yellow maca did not alter daily sperm production, and epididymal sperm motility was not affected by treatment with any ecotype of maca. Red maca, however, has no effect on sperm production. However, red maca has been shown to reduce prostate size in rats in which prostate hyperplasia had been induced with testosterone enanthate; yellow maca has shown moderate effects here, whereas black and yellow maca did not shown any effects. In-vivo studies in rats demonstrated that maca extract in doses up to 5 g/kg (equivalent to the intake of 770 g hypocotyls in a man of 70 kg) was safe and that higher effect on reproductive parameters was elicited with a dose of 1 g extract/kg corresponding to 2.2 g dry maca hypocotyls/kg (Chung et al. 2005). Almost all organ weights were similar in controls and in the maca extract-treated groups.

Acute and short-term administration of maca produced a small effect of male rat sexual

behaviour, and long-term administration did not increase anxiety or locomotion (Lentz et al. 2007). An increase in ejaculation latency and post-ejaculatory interval was observed after both acute and 7 days of treatment. Treating male rats by gavage with aqueous extract yellow and black maca increased epididymal sperm count and sperm count in vas deferens after 84 days of treatment without affecting daily sperm production (Gasco et al. 2007a). Maca appeared to act as a modulator of sperm count at the reproductive tract level. In another study, administration of the ethyl acetate fraction from the hydroalcoholic extract of black maca to male rats for 7 days increased daily sperm production and epididymal sperm count suggesting that the compounds related to the beneficial effect on sperm production of black maca were presented in this fraction (Yucra et al. 2008). Antioxidant components could play a role in the effect of increased epididymal sperm concentration observed in the model. Black maca increased stages of spermiation (VII–VIII) and mitosis of germ cells (IX–XI) in male rats, whereas camu camu fruit (*Myrciaria dubia*) increased stages of mitosis (IX–XI) and meiosis (XII) (Gonzales et al. 2013c). Mixture of maca + camu camu increased stages of spermiation, mitosis and meiosis. All treatments increased daily sperm production and epididymal sperm count. Total polyphenols, flavonoids levels and antioxidant activity were higher in camu than in black maca. They concluded that camu camu had potential effects improving spermatogenesis and co-administered with maca increased stages of mitosis, meiosis and spermiation of the spermatogenic cycle of rats. Administration of a hydroalcoholic extract of *Fagara tessmannii* (1 g) and *Lepidium meyenii* (black maca) (50 mg) together to rats significantly increased the number of spermatids, epididymis sperm count, daily sperm production and serum testosterone concentration when compared to the control (Lembè et al. 2014). The results indicated that the combination of *Lepidium meyenii* (black maca) with *Fagara tessmannii* could improve male reproductive organs activities in rats.

Administration of aqueous extract of yellow maca to adult female mice increased the litter size (Ruiz-Luna et al. 2005). Moreover, this treatment increased the uterine weight in ovariectomised animals. The results of the study confirmed for the first time some of the traditional uses of maca to enhance female fertility. In another study, administration of maca ethanol extract daily for 7 months ameliorated endocrine disruption after ovariectomy in rats (Zhang et al. 2008). Compared with the ovariectomised control rats, serum follicle-stimulating hormone level decreased markedly after treatment with 1.25 and 0.5 g/kg of maca extract; serum oestradiol level increased with 0.5 g/kg, but the serum testosterone level did not change at the end of 7th month. Also, maca extract decreased serum cholesterol and triglyceride levels at the end of 7th month. Lembè et al. (2012) found that female mice treated with black maca (BM) and *Turraeanthus africanus* (TA) significantly increased embryo implantation in pregnant mice and the uterine weight of non-pregnant mice compared to TA alone and control. The length of the oestrous cycle of BM+TA-treated mice was significantly shorten. At the pro-oestrous stage, the oestradiol level significantly increased in animals treated with BM+TA, and at oestrous stage only the oestradiol level of BM+T-treated animal significantly increased. Recent studies demonstrated that feeding female rats with 50 % maca powder for 7 weeks enhanced the luteinising hormone serum levels (4.5-fold) during the pro-oestrus luteinising hormone surge and follicle-stimulating hormone (19-fold) and acted in a pharmacological, dose-dependent manner (Uchiyama et al. 2014).

In a crossover design lasting for 23 weeks involving seventy-eight 55–84-week-old breeding bulls, maca diet supplementation had no direct effect on body weight, testes circumference, rectal temperature, mating behaviour and ejaculate volume (Clément et al. 2010b). However, supplementing maca in the first 10-week period increased the number of sperms in the second 10-week period, i.e. when the animals no longer received maca. The DNA fragmentation index and the visually assessed motility of the sperms

of bulls, that initially showed a borderline sperm quality, were significantly improved with early maca supplementation.

Clinical Studies

In a study of nine normal adult men, treatment with maca (1,500 or 3,000 mg/day) for 4 months resulted in increased seminal volume, sperm count per ejaculum, motile sperm count and sperm motility (Gonzales et al. 2001a). Serum luteinising hormone, follicle-stimulating hormone, prolactin, testosterone and oestradiol levels were not modified with maca treatment. In a 12-week double-blind, placebo-controlled, randomised, parallel trial of man aged between 21 and 56 years, an improvement in sexual desire was observed with maca after 8 weeks of treatment; however, maca treatment did not affect serum reproductive hormone (luteinising hormone, follicle-stimulating hormone, prolactin, 17-αhydroxyprogesterone, testosterone and 17-β-oestradiol) levels (Gonzales et al. 2002, 2003a). Maca was well tolerated and may also have a beneficial effect on libido. In another double-blind, randomised, placebo clinical trial on 50 adult Caucasian men affected by mild erectile dysfunction, 12 weeks supplementation with maca extract produced a small but significant improvement on subjective perception of general and sexual well-being in the adult patients (Zenico et al. 2009).

In a double-blind, placebo-corrected clinical pilot study of 20 Caucasian healthy early-postmenopausal women, administration of maca organic pre-gelatinised root powder (Maca-GO) capsules, the level of follicle-stimulating hormone (FSH) significantly decreased with a simultaneous significant increase in the luteinising hormone (LH) level, resulting in significant increase in both oestrogen (E2) and progesterone (PG), after 8 months treatment (Meissner et al. 2005, 2006c). Changes in hormone levels were accompanied by substantially reduced feeling of discomfort associated with menopause. The results showed that in addition to reduction in body weight, blood pressure, triglycerides and cholesterol levels and increasing serum HDL and iron, pre-gelatinised Maca-GO may be a valuable non-hormonal plant preparation for balancing levels of hormones (FSH, E2, PG and adrenocorticotropic hormone (ACTH)) and alleviating negative physiological and psychological symptoms (frequency of hot flushes, incidence in night sweating, interrupted sleep pattern, nervousness, depression and heart palpitations) experienced by women in perimenopausal stage. It appeared that Maca-GO may act as a toner of hormonal processes, leading to alleviation of discomfort felt by perimenopausal women, hence its potential use as non-hormonal alternative to HRT (hormone replacement therapy) programme. Similar results were obtained with in another double-blind, randomised, 4 months outpatient crossover configuration trial in which total of 34 Caucasian women volunteers participated (Meissner et al. 2006b). Two months application of Maca-GO stimulated production of E2; suppressed blood FSH, thyroid (T3) and ACTH, cortisol and body mass index; increased low-density lipoproteins and blood iron; and alleviated menopausal symptoms. Maca-GO noticeably increased bone density markers. The results suggested that Maca-GO applied to early-postmenopausal women (i) acted as a toner of hormonal processes along the hypothalamus–pituitary–ovarian axis, (ii) balanced hormone levels and (iii) relieved symptoms of menopausal discomfort (hot flushes and night sweating in particular), thus (iv) exhibited a distinctive function peculiar to adaptogens, providing an alternative non-hormonal plant option to reduce dependence on HRT. Similar results were obtained in a larger double-blind, randomised, placebo-corrected, outpatient, multi-centre (five sites) clinical study, in which a total of 168 Caucasian early-postmenopausal women volunteers (age >49 years) participated and 124 completed the study (Meissner et al. 2006a). Maca-GO significantly stimulated production of E2 with a simultaneous suppression of blood FSH, increase) in HDL. Maca-GO significantly reduced both frequency and severity of individual menopausal symptoms (hot flushes and night sweating in particular) resulting in significant alleviation of Kupperman's Index (from 22 to 10). In another randomised, double-blind, placebo-controlled, crossover trial of 14 post-

menopausal women, ingestion of powdered maca (3.5 g/day) for 6 weeks reduced psychological symptoms, including anxiety and depression, and lowered measures of sexual dysfunction in postmenopausal women independent of oestrogenic and androgenic activity (Brooks et al. 2008). In a double-blind, randomised, parallel group pilot dose-finding study of remitted depressed outpatients (17 women) with selective-serotonin reuptake inhibitor (SSRI)-induced sexual dysfunction, maca treatment was found to alleviate SSRI-induced sexual dysfunction in a dose-related manner (Dording et al. 2008).

In a randomised, double-blind, placebo-controlled crossover study of 29 postmenopausal Hong Kong Chinese women, maca treatment did not exert hormonal or immune biological action in the small cohort of patients; however, it appeared to reduce symptoms of depression and improve diastolic blood pressure (Stojanovska et al. 2014). Although results were comparable to previous similar published studies in postmenopausal women, there might be a cultural difference among the Chinese postmenopausal women in terms of symptom reporting.

Review Studies/Case Report/Patents

In a review of clinical evidence for or against the effectiveness of the maca plant as a treatment for sexual dysfunction, Shin et al. (2010) found four randomised clinical trials (RCTs) met all the inclusion criteria. Two RCTs suggested a significant positive effect of maca on sexual dysfunction or sexual desire in healthy menopausal women or healthy adult men, respectively, while the other RCT failed to show any effects in healthy cyclists. An RCT assessed the effects of maca in patients with erectile dysfunction using the International Index of Erectile Dysfunction-5 and showed significant effects. The results of the systematic review conducted by Lee et al. (2011) provided limited evidence for the effectiveness of maca as a treatment for menopausal symptoms as the total number of trials, the total sample size and the average methodological quality of the primary studies were too limited to draw firm conclusions. Beside, the safety issued has to be proven.

A young female with prolonged intermenstrual bleeding was found to have raised total plasma testosterone of 25.8 nmol/L (normal range <2.9 nmol/L) without clinical features of virulisation (Srikugan et al. 2011). Few months ago, investigations for lethargy and low libido had shown normal total testosterone of 0.8 nmol/L. Further history revealed that she was using maca extract to improve her lethargy and low libido. Reanalysis of the original serum sample using Elecsys testosterone II assay, a higher affinity assay, revealed a total testosterone level of 2.9 nmol/L. They concluded that it was important to exclude assay interference when testosterone level was greater than 5 nmol/L without supportive clinical signs.

An isolated composition obtained by extracting *Lepidium meyenii* roots with aqueous solvent, substantially free of cellulose, comprising benzyl isothiocyanate, *Lepidium* sterol component, *Lepidium* fatty acid component and macamide components, with claims of treating cancer and sexual dysfunction was lodged as separate claims with the US patent office (Zheng et al. 2001, 2002b; He et al. 2011).

Cognitive-Enhancing Activity

Black maca appeared to have more beneficial effects on latent learning in ovariectomised mice in the water finding task (Rubio et al. 2006a). All maca varieties showed antidepressant activity in the forced swimming test, reducing the time of immobility and increased uterine weight in ovariectomised mice. Aqueous and hydroalcoholic extracts of black maca significantly ameliorated the scopolamine-induced memory impairment in ovariectomised mice as measured in both the water Morris maze and the step-down avoidance tests (Rubio et al. 2007). Black maca extracts inhibited acetylcholinesterase activity, whereas monoamine oxidase activity was not affected. The results indicated that black maca improved scopolamine-induced memory deficits. In a subsequent paper, they reported that black maca aqueous extract improved experimental memory impairment induced by ovariectomy in female

mice in the water Morris maze and the step-down avoidance tests, attributed partly to its antioxidant and acetylcholinesterase inhibitory activities (Rubio et al. 2011a). Black maca decreased malondialdehyde and acetylcholinesterase levels in ovariectomised mice. The hydroalcoholic extract of black maca exhibited a dose–response effect in mice orally treated with 20 % ethanol as a model of memory impairment (Rubio et al. 2011b). Additionally, black maca and ascorbic acid ameliorated the deleterious effect of ethanol during the probe trial. The improvement of memory impairment by black maca could be attributed in part to its contents of polyphenolic compounds.

Neuroprotective/CNS Activity

Research showed that (1R,3S)-1-methyl-1,2,3,4-tetrahydro-β-carboline-3-carboxylic acid (MTCA) in maca was not neurotoxic, rather it improved memory and learning in mice (Rubio et al. 2006a, 2007) and had a favourable effect on the experimental mouse model for Alzheimer (Rubio et al. 2007); maca could provide a potential treatment for this pathology. Pentane maca extract exhibited a significant concentration-dependent neuroprotective effect on crayfish neurons subjected to hydrogen peroxide stress (Pino-Figueroa et al. 2010). Maca pentane extract administered intravenously to rats prior to and following middle cerebral artery occlusion decreased infarct volumes at low doses indicating a potential application of maca as a neuroprotectant. Studies by Vu (2012) reported that the pentane extract of maca and its macamides exerted dose-dependent fatty acid amide hydrolase (FAAH) inhibitory activity and may have potential applications as analgesics, antidepressants or anxiolytic agents. Concentration % response curve for the inhibition of human FAAH by maca pentane extract was in the range from 0.3 to 30 μg/mL with IC_{50} = 7.5 μg/m. FAAH IC_{50} values and maximal inhibitory activity of selected macamides were, respectively, as follows: *N*-benzyl-9*Z*-octadecenamide 14.18 μM, 761.3 %; *N*-(3-methoxybenzyl)-9*Z*-octadecanamide 7.84 μM, 76.39 %; *N*-benzyl-(9*Z*,12*Z*)-octadecadienamide 6.91 μM, 83.20 %; *N*-(3-methoxybenzyl)-(9z,12*Z*)-octadecadienamide 7.24 μM, 87.50 %; *N*-benzyl-(9*Z*, 12*Z*, 15*Z*)-octadecatrienamide 26.94 μM, 79.71 %; *N*-(3-methoxybenzyl)-(9*Z*,12*Z*,15*Z*)-octadecatrienamide 11.76 μM, 82.78 %; and *N*-pyridine-9*Z*-octadecanamide 6.74 μM, 901.0 %. Pretreament of B-35 neuroblastoma cell line with maca pentane extract (5–50 μg/mL) and its component macamide *N*-(3-methoxybenzyl)palmitamide (1–30 μM) prior to exposure to a neurotoxic concentration (10 μM) of amyloid-beta (Aβ) (25–35) counteracted the toxicity produced by Aβ (25–35), demonstrating significant increases in cell viability (34 % and 21 %, respectively) (Alquraini et al. 2014). When the tested compounds were evaluated for antioxidant activity and their effects on caspase 3, neither the maca extract nor *N*-(3-methoxybenzyl)palmitamide demonstrated an antioxidant effect or caspase 3 inhibition suggesting that other mechanisms were involved in their neuroprotective action.

N-3-methoxybenzyl-linoleamide, an active maca macamide, displayed significant time-dependent and dose-dependent FAAH activity (Almukadi et al. 2013). The mechanism of inhibition was most likely irreversible or slowly reversible. These results suggested the potential application of macamides isolated from maca as FAAH inhibitors, as they might act on the central nervous system to provide analgesic, anti-inflammatory or neuroprotective effects, by modulating the release of neurotransmitter. Wu et al. (2013) synthesised 11 of the 19 reported macamides in *L. meyenii* and found them to be potential inhibitors of the human enzyme, FAAH. The following four most active macamides inhibited FAAH with IC_{50} values in the 10–14 μmolar range: the *N*-benzylamide of linoleic acid and the *N*-(3 methoxybenzyl) amides of oleic, linoleic and linolenic acids. Somewhat less active were the *N*-benzylamide of oleic acid (IC_{50} = 17 μmolar) and the *N*-benzylamide of linolenic acid (IC_{50} = 42 μmolar). Of the three compounds evaluated in a preincubation time study, two macamides were not irreversible inhibitors of FAAH. The third, a carbamate structurally related to macamides, was shown to be an irreversible inhibitor of FAAH (IC_{50} = 0.153 μM).

Of the macamides (N-alkylamides) isolated from maca roots, *N*-(3-methoxybenzyl)-(9*Z*,12*Z*,15*Z*)-octadecatrienamide (5), *N*-benzyl-(9*Z*,12*Z*,15*Z*)-octadecatrienamide (6), and *N*-benzyl-(9*Z*,12*Z*)-octadecadienamide (7), compound 7 showed submicromolar and selective binding affinities for the cannabinoid CB1 receptor (Ki value of 0.48 μM) (Hadju et al. 2014). Notably, compound 7 also exhibited weak fatty acid amide hydrolase (FAAH) inhibition (IC_50 = 4 μM) and a potent inhibition of anandamide cellular uptake (IC_{50} = 0.67 μM). The pronounced endocannabinoid system polypharmacology of compound 7 highlighted the potential involvement of the arachidonoyl-mimicking 9*Z*,12*Z* double-bond system in the linoleoyl group for the overall cannabimimetic action of N-alkylamides in Peruvian maca roots.

In mice exposed to chronic unpredictable mild stress, maca extract (250 and 500 mg/kg) significantly decreased the duration of immobility time in the tail suspension test (Ai et al. 2014). After treatment with maca extract (250 and 500 mg/kg), the granule cell layer in the dentate gyrus appeared thicker. Maca extract (250 and 500 mg/kg) also induced a significant reduction in corticosterone levels in mouse serum. In mouse brain tissue, after 6 weeks of treatment, noradrenaline and dopamine levels were increased by maca extract, and the activity of reactive oxygen species was significantly inhibited. Serotonin levels were not significantly altered. These results demonstrated that maca extract (250 and 500 mg/kg) showed antidepressant-like effects and was related to the activation of both noradrenergic and dopaminergic systems, as well as attenuation of oxidative stress in mouse brain.

Adaptogenic Activity

Animal studies showed that dry maca powder had antifatigue effect (Yu and Jin 2004). It was found to contain various antifatigue substances such as branched-chain amino acids (BCAA), taurine and zinc; and its protein content reached 8.87 %. Maca was found to restore homeostasis impaired by restraint stress (López-Fando et al. 2004). It attenuated or abolished stress-induced ulcers, elevated corticosterone levels, the reduction of glucose and the increase in the weight of adrenal glands produced by stress. It also eliminated the decrease in free fatty acids (FFA) in plasma produced by stress, and a positive result was obtained in the forced swimming test. Supplementation of maca extract increased swimming endurance capacity by increasing the swimming time to exhaustion in rats (Choi et al. 2012). Lipid-soluble maca extract attenuated exercise-induced oxidative stress. Supplementation with 100 mg/kg of maca extract reduced serum lactate dehydrogenase activity and muscle lipid peroxidation and increased hepatic and muscle total glutathione compared with those values in controls.

Aqueous maca extract was found to enhance the energy of mouse in the forced swimming test (Zheng et al. 2002a). Oral administration of aqueous extracts, MacaForce™ AQ-1, AQ-2, AQ-3 and AQ-4, showed that the increase in swim time was directly related to the increase in content of polysaccharides in the aqueous extracts. Increase in serum lactate dehydrogenase (LDH) activity and decrease in the concentration of serum lactic acid were dose related with the content of potential active constituents. Administration of aqueous yellow maca extract (0.8 and 1.2 mg maca/g) to newly weaned male rats for 30 days elicited an adaptogenic effect by enhancing their endurance in the swimming test through reduction of oxidative stress (reducing superoxide dismutase, catalase and lactate dehydrogenase enzyme activities and lipid peroxidation (TBARS)) (Suárez et al. 2009).

In a pilot trial, Stone et al. (2009) found that 14 days maca extract supplementation significantly improved 40 km cycling time trial endurance performance and sexual desire in trained male cyclists.

Anti-hypertriglyceridaemic/ Antiatherogenic Activity

Administration of maca extract to hereditary hypertriglyceridaemic (HHTg) rats significantly decreased the levels of VLDL (very low-density

lipoproteins), LDL (low-density lipoproteins) and total cholesterol and also the level of TAG (triacylglycerols) in the plasma, VLDL and liver (Vecera et al. 2007). Maca, as well as rosiglitazone (positive control), significantly improved glucose tolerance, as the decrease of AUC (area under the curve) of glucose showed, and lowered levels of glucose in blood. The activity of SOD (superoxide dismutase) in the liver, the GPX (glutathione peroxidase) in the blood and the level of GSH (glutathione) in liver increased in all cases significantly. Results demonstrated that maca appeared to have a potential as a positive influence on chronic human diseases (characterised by atherogenous lipoprotein profile, aggravated antioxidative status and impaired glucose tolerance) and their prevention.

In a randomised placebo-controlled 90-day study of patients suffering from the metabolic syndrome, no adverse effects were found in volunteers using silymarin (0.8 g/day), silymarin+yacon (0.8 g/day) and silymarin+maca (0.6 g/day) for the prevention of diseases with a proatherogenic lipoprotein profile and liver steatosis (Valentová et al. 2008). A moderate AST (aspartate aminotransferase) level and diastolic blood pressure increase were found in volunteers using high doses of maca powder (0.6 g/day), but this effect could be reversed by supplementation with silymarin.

Antidiabetic Activity

Black maca (BM), yacon and the mixture of both extracts reduced glucose levels in streptozotocin-diabetic mice (Gonzales et al. 2013a). Non-diabetic mice treated with BM and yacon showed higher daily sperm production (DSP) than those treated with vehicle. Diabetic mice treated with BM, yacon and the mixture maca/yacon increased DSP and sperm count in vas deferens and epididymis with respect to non-diabetic and diabetic mice treated with vehicle. The combination of two extracts improved glycaemic levels and male reproductive function in diabetic mice. Streptozotocin increased 1.43 times the liver weight that was reversed with both plants extracts.

Anti-inflammatory Activity

Oral administration of maca extract significantly relieved the symptoms of diarrhoea and rectal bleeding and reduced colonic myeloperoxidase activity in dextran sodium sulfate (DSS)-induced colitis in mice (Cho et al. 2013). Maca extract treatment inhibited expression of several colonic proteins related to inflammatory responses, such as interleukin (IL)-1β, tumour necrosis factor-α, IL-6 and S100 calcium-binding protein A8, whose expressions were increased significantly by DSS treatment. These results suggested that maca extract could alleviate DSS-induced colitis in mice by modulating colonic inflammatory mediators.

In a Mumbai-based, multi-centre, randomised, double-blind study of 95 subjects, treatments with Reparagen (a polyherbal consisting of 300 mg of *Uncaria guianensis* and 1,500 mg of *Lepidium meyenii*) and glucosamine sulfate, twice daily for up to 8 weeks, produced substantial improvements in pain, stiffness and function in subjects with osteoarthritis with 45–62 % reduction in WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) or VAS (visual analogue score) scores (Mehta et al. 2007). Response rates were high, and the safety profile was excellent, with significantly less rescue medication use with Reparagen.

Antihypertensive Activity

Maca was one of several medicinal plants used in Latin America, reported to inhibit significantly the hypertension relevant angiotensin I-converting enzyme (ACE) (Ranilla et al. 2010).

Osteoprotective Activity

Studies showed that administration of a high dose of maca ethanol extract (0.28 g/kg) for 28 weeks effective in preventing oestrogen deficient bone loss in ovariectomised rats (Zhang et al. 2006). Red and black maca exhibited protective effects on bone architecture in ovariectomised rats by reversing the adverse effect of ovariectomy on

weight, diameter and width of the femoral bone without showing oestrogenic effects on uterine weight (Gonzales et al. 2010). Maca treatment also reversed the effect of ovariectomy by increasing the trabecular bone area in the second lumbar vertebra. Studies by Wang et al. (2009) found that dietary supplementation of ovariectomised rats for 7 weeks with maca may have potential effects on prevention from postmenopausal lipid abnormality and bone metabolism via a different mechanism from oestrogen.

Immunomodulatory Activity

Supplementation of the diet of mice intraperitoneally inoculated with *Staphylococcus aureus* with maca or uña de gato (*Uncaria tomentosa*) significantly increased the number of peritoneal macrophages and body weight (Guerra et al. 2002). The experimental groups fed with maca or uña de gato had 46.2 % and 52.4 % of active macrophages, respectively, versus 32.8 % in the control group. Oral administration of ethanol maca extract to mice significantly increased the rate of transformation of lymphocyte induced by phytohaemagglutinin, and it also promoted production of haemolysin in serum and antibody-producing cell in the spleen (Zhang et al. 2007). The study suggested that ethanol maca extract may enhance cellular and humoral immunity function in mice. Feeding mice with maca powder and ginsenosides from Panax ginseng was found to enhance the immune function (Jin et al. 2007b). Mice fed with powdered maca, ginsenosides or a combination had increases of Con A-induced lymphocyte proliferation and total haemolytic complement value, as well as higher peritoneal macrophage function and NK (natural killer) cell activity.

Photoprotective Activity

Maca extracts were found to protect the skin of rats against UV irradiations and could be suggested as an alternative means of solar protection (Gonzales-Castañeda and Gonzales 2008). The aqueous extract of maca after a boiling process had better effect than maca extract without a boiling process. A dose–response effect was observed with increasing doses of aqueous extract of maca after a boiling process. Maca extract was found to possess benzyl glucosinolates and polyphenols. Gonzales-Castañeda et al. (2011) reported that leaf extracts of three maca varieties prevented the development of sunburn cells, epidermal hyperplasia, leucocytic infiltration and other alterations produced by UVB radiation in mice. Mice treated with black maca showed the highest superoxide dismutase levels, and mice treated with black and yellow maca showed higher catalase levels in skin, whereas red maca protected the skin and liver against significant increases in the lipid peroxidation activity observed in the unprotected animals.

Cosmetics Uses

Compositions containing papain-treated papaya (*Carica papaya*) powders, papain-treated maca (*L. meyenii*) powders, papain and substantially water-free powders or oils that would be useful as face cleansers, packs and bath preparations with skin-conditioning effects had been lodged with the Japanese Patent Office (Arita and Hirao 2003). A face cleanser prepared from mannitol, soap, kaolin, talc, olive oil, papain, papain-treated papaya powder and papain-treated maca powder with the addition of polyols, mucopolysaccharides, sugars and/or amino acids to the extract was reported to improve the skin-moisturising effect (Hiroshi et al. 2003). Mitsuma and Hirao (2001) had lodged a claim with the Japanese Patent Office pertaining to the skin-lightening, rough skin-treating and moisturising cosmetics containing extract of *Lepidium meyenii*. The water extract of *L. meyenii* inhibited tyrosinase, a key enzyme in the production of the skin pigment melanin, with an IC_{50} of 150 μg/mL.

Activity of 1-Methyl-1,2,3,4-Tetrahydro-β-Carboline-3-Carboxylic Acid (MTCA)

1-Methyl-1,2,3,4-tetrahydro-β-carboline-3-carboxylic acid (MTCA), a tetrahydro-β-carboline found in maca and other crops, was reported to be

both a helpful and harmful compound and was suggested to be co-mutagenic or a precursor to mutagenic compounds, causing neuronal death in-vitro or could be bioactivated giving rise to endotoxins (Gonzales and Gonzales-Castañeda 2009). They found no toxicity on consumption of maca, suggesting that when consumed as multi-component, MTCA may lose its adversity as drug action. Conflicting observations necessitated research to determine the true actions of MTCA in the human body. Manabe et al. (1996) suggested that accumulation of high MTCA levels in the eyes correlated with the development of cataracts. However, subsequent studies had demonstrated that MTCA had antioxidant capacity greater than that of vitamin E. Pari et al. (2000) found that β-carbolines like MTCA accumulated in human tissues and may serve a protective role against oxidative stress. They quenched singlet oxygen, superoxide and hydroxyl radicals and inhibited the oxidative formation of higher-molecular-weight aggregates of the test protein, eye lens gamma-crystallin. Studies by Ichikawa et al. (2006) found that 1-methyl-1,2,3,4-tetrahydro-β-carboline-3-carboxylic acid (MTCA), also found in aged garlic, demonstrated strong hydrogen peroxide scavenging and inhibited LPS-induced nitrite production preventing the conversion of the MTCA to other non-beneficial metabolites.

Tetrahydro-β-carbolineslike1,2,3,4-tetrahydro-β-carboline-3-carboxylic acid (THCA) and 1-methyl-1,2,3,4-tetrahydro-β-carboline-3-carboxylic acid (MTCA), two diastereoisomers (1S,3S and 1R,3S), were found in μg/g in commercial fruits like citrus, banana, grapes, tomatoes and apples (Herraiz 1999) and fruit juices (Herraiz and Galisteo 2003). Tetrahydro-β-carbolines (THbetaCs) like 6-hydroxy-1-methyl-1,2,3,4-tetrahydro-β-carboline (6OHMTHbetaC), 1,2,3, 4-tetrahydro-β-carboline-3-carboxylic acid (THCA), 1-methyl-1,2,3, 4-tetrahydro-β-carboline-3-carboxylic acid (MTCA) in both diastereoisomers (1S,3S and 1R,3S) and 1-methyl-1,2,3, 4-tetrahydro-β-carboline were also found in dark chocolate, milk chocolate, cocoa and chocolate-containing cereals (Herraiz 2000). These biological active alkaloids had been reported to accumulate in the mammalian tissues, fluids and brain. Herraiz and Galisteo (2003) found that they acted as antioxidants and free radical scavengers in the ABTS assay when compared with ascorbic acid and Trolox, suggesting that tetrahydro-beta-carboline alkaloids might act as antioxidants when absorbed and accumulated in the body, contributing to the antioxidant effect of fruit products containing these compounds. The mutagenic effect of MTCA on *Salmonella typhimurium* TA100 in the absence of S9 had been described in Japanese soy sauce treated with exogenous nitrites (Wakabayashi et al. 1983, 1984). The mutagen produced from (−)-(1S,3S)-MTCA with nitrite was a minor product(s), the major product being the non-mutagen (−)-(1S,3S)-1-methyl-2-nitroso-1,2,3,4-tetrahydro-β-carboline-3-carbo xylic acid [(−)-(1S,3S)-MNTCA. However, MTCA was found not mutagenic on *S. typhimurium* TA100 in the absence of the nitrites, with or without S9 (Ichikawa et al. 2006). Further, Higashimoto demonstrated that the mutagenicity of 1-methyl-1,2,3, 4-tetrahydro-beta-carboline-3-carboxylic acid (MTCCA), a major mutagen precursor in soy sauce on treatment with nitrite and ethanol, was strongly decreased by the addition of hot water extracts of green, black and oolong teas in the reaction mixture. Their findings suggested that the mutagenicity of MTCCA on treatment with nitrite in the presence of ethanol may be decreased by the mixed fractions of lyophilic components such as polyphenols, which have high reducing power such as catechins and the other compounds which have little reducing power including the derivatives of the catechins.

Effect on Health Status and Growth

A nutritional evaluation study of maca in albino mice found that mice given cooked maca had the best growth curve, while mice fed commercial balanced food (CBF) had better growth then the raw maca group (Canales et al. 2000). The serum values of total proteins and albumin were statistically superior for the mice group eating cooked maca than that of the raw maca and CBF groups.

No signs of malnutrition nor overweight were observed in any of the groups.

In a survey of the health status of 27 maca consumers and 23 nonconsumers living in the Peruvian Central Highlands, testosterone/oestradiol ratio, interleukin IL-6 and chronic mountain sickness score were lower, whereas the health status score was higher, in maca consumers when compared to nonconsumers (Gonzaels et al. 2013b).

Maca and Dyspepsia

A 4-week long treatment with Maca did not produce significant changes on gastric mucosa of patients (29) with functional dyspepsia, neither on *Helicobacter pylori* eradication (Benites Goñi et al. 2014).

Toxicity Studies

Maca had been reported in the scientific literature to have a low degree of acute oral toxicity in animals and low cellular toxicity in-vitro (Valerio and Gonzales 2005). Freeze-dried maca aqueous extract of maca (1 g/kg BW) did not reveal any toxic effect on the normal development of pre-implanted mouse embryos in mice (D'Arrigo et al. 2004).

Traditional Medicinal Uses

Maca has been used traditionally by Andean Indians as a food and an essential folk medicine for thousands of years (Leon 1964; Ochoa 2001; Gonzales 2012). The tuber of the maca has had popular use for hundreds of years for medicinal purposes, to increase fertility in man and animals (Leon 1964). The Kallawaya, travelling healers in the Andes, prescribed the fresh tuber cut into fine slices, in decoction, 3 or 4 days after the last menstrual period for sterile women wishing to become pregnant (Girault 1984). Maca has been prescribed as an adaptogen, an immunostimulant, an anabolic, in menopause and for influence on hormonal balance (Quir'os and Aliaga 1997). Maca has been recommended for treating malabsorption syndrome and protein deficiency disease, during chemotherapy for leukaemia, in AIDS treatment and for alcoholism and menopausal anaemia (Chacón de Popovici 1997). It has also been used to treat chronic polyarthritis, during allergy attacks and as a laxative (Aliaga and Aliaga 1998). Native Indians used Maca to treat anaemia, tuberculosis, sterility and fatigue (Cicero et al. 2001). Maca has traditionally been employed for its purported aphrodisiac and fertility-enhancing properties (Bogani et al. 2006). For generations, people of the rural community in Peru have used Maca, because of their belief that it improves fertility and sexual desire (Lentz et al. 2007). It is also recommended in traditional medicine as an effective agent for cancer prevention and treatment, anaemia, gastritis and depression (Wang et al. 2007). Maca is used to enhance sexual behaviour, fertility and energy and to reduce stress and menopausal symptoms (Cho et al. 2013). In the United States, maca has become known as a libido booster and also known for its effects on energy and endurance (Kilham 2002).

Other Uses

Miscellaneous potential non-edible uses of maca have also been reported.

Maca oil has cyanobactericidal and antitermite activity. The oil of maca aerial parts was selectively toxic towards the cyanobacterium *Oscillatoria perornata* compared to the green alga *Selenastrum capricornutum*, with complete growth inhibition at 100 µg/mL (Tellez et al. 2002). Mortality of the Formosan subterranean termite, *Coptotermes formosanus*, was numerically, but not significantly, higher when held on filter paper treated with maca oil. At 1 % (w/w), maca oil also appeared to act as a feeding deterrent to termites. Several minor components of the essential oil of maca including 3-methoxyphenylacetonitrile and benzyl thiocyanate were significantly active against the Formosan termite.

Studies by Lee et al. (2005) found that certain compounds in maca meal had growth-enhancing effects in rainbow trout (*Oncorhynchus mykiss*)

juveniles. Feed conversion ratio (FCR) and protein efficiency ratio (PER) were also significantly improved in the fish fed maca meal diets.

Studies by Saldaña et al. (2006) showed the potential usefulness of maca to be used as a culture medium for the study of *Trypanosoma cruzi*. They found the inclusion of maca in the culture media facilitated *Trypanosoma cruzi* growth; it was determined that the medium containing blood-enriched maca among its solid components and a maca infusion in the liquid phase had better growth ($3{,}41 \times 10^5$ parasites/mL) compared to the other culture media after 5 days.

Comments

Fifty native and 12 naturalised species of *Lepidium* grow in South America (Al-Shehbaz 2010). *Lepidium peruvianum* was one of 17 taxa reduced to synonymy.

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Raphanus raphanistrum subsp. *sativus*

Scientific Name

***Raphanus raphanistrum* subsp. *sativus* (L.) Domin**

Synonyms

Raphanistrum gayanum Fisch. & C.A.Mey., *Raphanus acanthiformis* Morel ex L.Sisley, *Raphanus acanthiformis* J.M. Morel ex Sasaki, *Raphanus acanthiformis* var. *raphanistroides* (Makino) Hara, *Raphanus candidus* Vorosch., *Raphanus chinensis* Mill., *Raphanus gayanus* (Fisch. & C.A.Mey.) G.Don, *Raphanus macropodus* H.Lév., *Raphanus niger* Mill., *Raphanus oleifer* Steud., *Raphanus orbicularis* Mill., *Raphanus radicula* Pers., *Raphanus raphanistroides* (Makino) Nakai, *Raphanus raphanistrum* var. *sativus* (L.) Schmalh., *Raphanus raphanistrum* subsp. *sativus* Schmalh., *Raphanus raphanistrum* var. *sativus* (L.) Domin, *Raphanus raphanistrum* var. *sativus* (L.) Beck, *Raphanus rotundus* Mill., *Raphanus sativus* L., *Raphanus sativus* subsp. *esculentus* Metzg., *Raphanus sativus* var. *longipinnatus* L.H.Bailey, *Raphanus sativus* var. *macropodus* (H.Lév.) Makino, *Raphanus sativus* var. *niger* (Mill.) J.Kern., *Raphanus sativus* var. *radicula* Pers., *Raphanus sativus* var. *raphanistroides* (Makino) Makino, *Raphanus sativus* f. *raphanistroides* Makino, *Raphanus sativus* subsp. *sinensis* Sazonova & Stank., *Raphanus sinensis* Thunb. ex Pritz., *Raphanus taquetii* H.Lév.

Family

Brassicaceae

Common/English Names

Chinese Radish, Common Radish, Daikon, Daikon Radish, Fodder Radish, Garden Radish, Japanese Radish, Leafy Daikon, Oriental Radish, Oriental Winter Radish, Radish, Wild Radish

Vernacular Names

Arabic: Fejil, Fijil, Fujl
Azerbaijan: Qırmızı turp, Turp
Brazil: Rabanete
Burmese: Monla
Chinese: Hung Loh Paak Tsai, Hong Luo Bo Zi, Lai Fu, Lai-Fu-Tzu Ts-Ao, Loh Bak, Luo Bo, Ou Zhou Luo Bo
Croatian: Rotkva, Rotkvica
Czech: Ředkvièka, Ředkev Seta
Danish: Haveræddike, Kinaræddike, Ræddike, Radis, Radise, Japanræddike
Dutch: Radijs, Ramenas, Tamme Radÿs
Esperanto: Rafano, Rafano Kultiva, Rafano Manĝebla, Rafaneto
Estonian: Redis
Euskera: Arapa, Erradilla, Erraso, Errasu, Errefau, Errefaun, Erresan, Erresana, Erresauchoa, Erresaun, Erresauna, Erresautxo, Lutxarbi

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Finnish: Retiisi, Retikka, Ruokaretikka
French: Petit Radis, Radis, Rave, Radis Cultivé, Radis D'été, Radis Rose
Galician: Labestro, Rábano, Rabâo, Rábâo, Ravo, Saramago
German: Bierrettich, Bierwurz, Furzwurzel, Garten-Rettich, Monatsrettich, Radi, Radieschen, Rettich, Retwurzel
Greek: Rapani
Hebrew: Tznonit
Hornjoserbsce (***Upper Sorbian***): Zahrodna Rjetkej
Hungarian: Retek
Icelandic: Ætihreòka, Hreðka, Raefla
India: Mulō, Mulla (Bengali), Mooli, Muli, Mūlī, Mulla (Hindi), Mullangi (Malayalam), Mūlaka (Marathi), Mūlī (Punjabi), Muulaka (Sanskrit), Muulam, Mullangi, Mullanggki (Tamil), Mullangi (Telugu), Mūlī (Urdu)
Indonesia: Lobak, Lobak Berem, Lobak Putih, Luba (Malay) Lobak, Rades (Javanese), Lobak Berem, (Sundanese)
Italian: Rafano, Ramolaccio, Ravanello, Ravanello Commune
Japanese: Daikon, Hatsuka Daikon, Radeisshu
Khmer: Chhaay Thaw
Kurdish: Tūr
Korean: Il Mu, Mu
Laotian: Kaad Khaaw
Latvian: Redīss
Lithuanian: Valgomasis Ridikas
Malaysia: Lobak, Lobak Putih, Lobak Merah, Luba
Nepalese: Mulo
Norwegian: Hagereddik, Reddik
Persian: Torobcheh
Polish: Rzodkiew, Rzodkiewka
Philippines: Rabanos (Cebu Bisaya), Labanos (Tagalog)
Portuguese: Raba, Rabanete, Rabanetes Escarlate, Rábano, Rabão, Rabâo Radisio, Rabiça, Rabiças, Rabo
Romanian: Ridiche
Russian: Red'ka, Red'ka Ogorodnaia, Red'ka Posevnaia
Sardinian: Ravanella
Scots: Reefort
Serbian: Rotkvica, Trotkvica
Slovak: Reďkev, Redkev Vrtna, Redkvica, Vrtna Redkev
Slovenian: Retvica
Spanish: Erradil, Labrestos, Matacandil, Rabanillo, Rabanito, Rabaniza, Rábano, Rábano Blanco, Rábano Blanco Redondo, Rábano Castellano, Rábano Colorado Redondo, Rábano Común, Rábano Encarnado, Rábano Granadino, Rábano Largo, Rábano Macho, Rábano Pajizo, Rábano Redondo, Rábano Silvestre, Rábanos, Zanahoria
Sri Lanka: Rabu (Sinhalese)
Swedish: Rädisa
Thai: Hua Phak Kat Khao, Hua Pàk Gàat Kaao, Hua Chai Táo, Ma Puek (Chiang Mai), Phak Kat Hua (Central), Phak Poek Hua (Northern)
Turkish: Trup, Tūrp
Vietnamese: Củ Cải, Củ Dền, Rađi
Welsh: Heddig, Radys, Redis, Redyns, Rhodri Rhuddygl

Origin/Distribution

The exact origin or radish is unknown because it has been in cultivation for thousands of years. Radish is thought to have originated in the eastern Mediterranean region and has been domesticated in Europe in the pre-Roman times.

DNA sequence study from different organelles by Yang et al. (2000) suggested *Raphanus sativus* to be a hybrid between *B. rapa*/*B. oleracea* and *B. nigra* lineages as proposed by Song et al. (1990).

Agroecology

Radish tolerates a wide range of climatic regimes. Radish flourishes in full sun and in well-drained, light sandy loams with pH of 6.5–7. In temperate areas, radish is usually planted out a few weeks prior to spring before the first frost. In warm weather, they are normally planted out in fall.

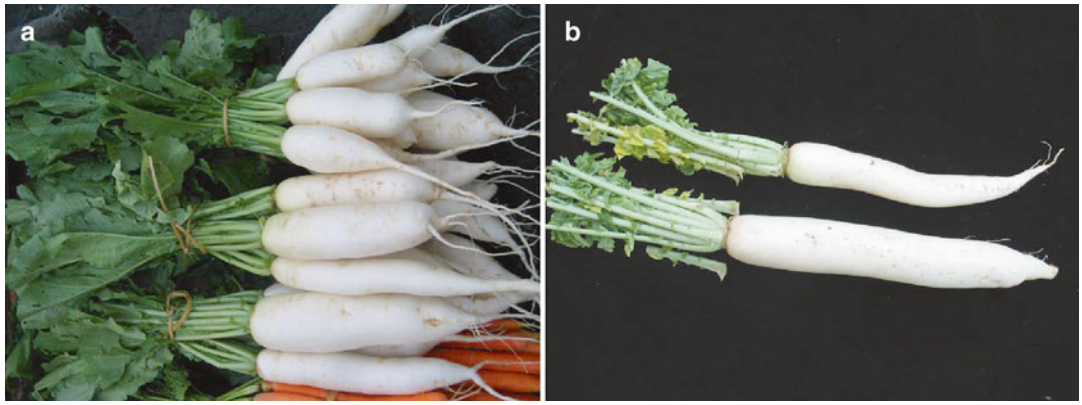

Plate 1 (**a**, **b**) Chinese radish (lobak)

Edible Plant Parts and Uses

Radish roots, seed sprouts, leaves, flowers and seeds are edible. Radish roots are eaten raw, baked, roasted or cooked in stews, soups or stir fries, also lightly steamed with olive oil, salt or lemon juice. Radish is eaten raw with a dip or with peanut butter, shredded to salads, pickled in kimchi and made into radish cakes like Japanese diakon mocha. A number of pickled radish products are produced in Korea such as *kaktugi*, *tongchimi*, *chonggak-kimchi*, *seok-bakji*, *yolmu-kimchi dan moogi kach doo ki gac-tuki and mootsanji. Sinki* is a sour pickle prepared from radish taproots and is consumed traditionally in India, Nepal and parts of Bhutan, where it is used as a base for soup or eaten as a pickle.

Young leaves are also eaten raw or cooked as greens. Radish greens are also blended into smoothies. The blossoms are edible, and the seed pods have many uses, eaten raw, cooked, in stir fries to pickles.

Plate 2 Daikon plant

Botany

An annual or biennial coarse herb, 30–120 cm tall, glabrous, scabrous or hispid with stout, erect, branched stem. Roots are fleshy; swollen; white, pink, red or black; linear; fusiform; oblong; or globose, 1–100×0.5–45 cm, sometimes slender and not fleshy (Plates 1, 2, 3, 4 and 5). Lower leaves are lyrate-pinnatifid, petiolate, sparsely hirsute to glabrous; the lobes are dentate or denticulate (Plates 2 and 6). The uppermost cauline leaves are subsessile, often undivided and dentate. Racemes are elongated, narrowly erect, oblong, glabrous or sparsely hirsute; petals are purplish, pink to nearly white (Plate 7), with dark purple veins, 1.5–2 cm long, broadly obovate with a long narrowed claw; filaments are slender and anthers are sagittate at the base, style, stigma entire. Fruit is indehiscent, silique fusiform, lanceolate and cylindrical to conical, tapering from above base to a narrow beak. Seeds are 2–4, globose or ovoid, somewhat ridged, 2.5–4 mm in diameter.

Plate 3 Daikon radish

Plate 4 European radish with small short cylindrical red roots

Plate 5 European radish with small globose red roots

Plate 6 Radish leaves

Plate 7 Radish flowers

Nutritive/Medicinal Properties

Nutrients/Phytochemicals: Root

The proximate nutrient composition per 100 g edible portion of raw radish was reported as water 95.2 g, energy 16 kcal (66 kJ), protein 0.68 g, total lipid 0.10 g, ash 0.55 g, carbohydrate 3.4 g and total dietary fibre 1.6; total sugars 1.86 g, sucrose 0.10 g, glucose 1.05 g and fructose 0.71 g; minerals, Ca 25 mg, Fe 0.34 mg, Mg 10 mg, P 20 mg, K 233 mg, Na 39 mg, Zn 0.28 mg, Cu 0.050 mg, Mn 0.069 mg and Se 0.6 μg; vitamins, vitamin C 14.8 mg, thiamine 0.012 mg, riboflavin 0.039 mg, niacin 0.254 mg, pantothenic acid 0.165 mg, vitamin B6 0.071 mg, total folate 25 μg, total choline 12.3 mg, β-carotene 4 μg, vitamin A 7 IU, vitamin K (phylloquinone) 1.3 μg, β-carotene 22 μg, lutein + zeaxanthin 10 μg and phytosterols 7 mg; total

saturated fatty acids 0.032 g, 16:0 (palmitic acid) 0.027 g, and 18:0 (stearic acid) 0.004 g; total monounsaturated fatty acids 0.017 g, 18:1 undifferentiated (oleic acid) 0.017 g; and total polyunsaturated fatty acids 0.048 g, 18:2 undifferentiated (linoleic acid) 0.017 g and 18:3 undifferentiated (linolenic acid) 0.031 g; and amino acids, tryptophan 0.009 g, threonine 0.023 g, isoleucine 0.020 g, leucine 0.031 g, lysine 0.033 g, methionine 0.010 g, cystine 0.010 g, phenylalanine 0.036 g, tyrosine 0.009 g, valine 0.035 g, arginine 0.038 g, histidine 0.013 g, alanine 0.26 g, aspartic acid 0.064 g, glutamic acid 0.157 g, glycine 0.026 g, proline 0.022 g and serine 0.278 g (USDA ARS 2013). Radish was also found to contain 0.4–2.11 mg/100 g FW of the flavonol kaempferol FW (Bilyk and Sapers 1985; Hertog et al. 1992; Lugasi and Hovari 2000). Radish leaves and sprouts were found to contain 7.72 mg/100 g and 13.76–35.128 72 mg/100 g kaempferol, respectively (Sakakibara et al. 2003).

The proximate value per 100 g edible portion of raw oriental radish was reported as water 94.62 g, energy 18 kcal (76 kJ), protein 0.60 g, total lipid 0.10 g, ash 0.58 g, carbohydrate 4.1 g, total dietary fibre 1.6 and total sugars 2.5 g; minerals, Ca 27 mg, Fe 0.4 mg, Mg 16 mg, P 23 mg, K 227 mg, Na 21 mg, Zn 0.15 mg, Cu 0.115 mg, Mn 0.038 mg and Se 0.7 μg; vitamins, vitamin C 22 mg, thiamine 0.02 mg, riboflavin 0.02 mg, niacin 0.2 mg, pantothenic acid 0.138 mg, vitamin B6 0.046 mg, total folate 7.3 μg, betaine 0.1 mg, total choline 12.3 mg and vitamin K (phylloquinone) 0.3 μg; total saturated fatty acids 0.03 g, 16:0 (palmitic acid) 0.026 g and 18:0 (stearic acid) 0.004 g; total monounsaturated fatty acids 0.017 g, 18:1 undifferentiated (oleic acid) 0.017 g; total polyunsaturated fatty acids 0.045 g, 18:2 undifferentiated (linoleic acid) 0.016 g and 18:3 undifferentiated (linolenic acid) 0.029 g; and amino acids, tryptophan 0.003 g, threonine 0.025 g,, isoleucine 0.026 g, leucine 0.031 g, lysine 0.030 g, methionine 0.006 g, cystine 0.005 g, phenylalanine 0.020 g, tyrosine 0.011 g, valine 0.028 g, arginine 0.035 g, histidine 0.011 g, alanine 0.19 g, aspartic acid 0.041 g, glutamic acid 0.113 g, glycine 0.019 g, proline 0.015 g and serine 0.018 g (USDA ARS 2013).

Among the seven Japanese radish cultivars, Koshin, Kouto and Shogoin were the three highest in terms of the total soluble sugar (glucose, fructose, sucrose) content (Hara et al. 2011). Sobutori, which is the most common radish cultivar in Japan, was the lowest. The total organic acid (malate, citrate, ascorbate, lactate and pyruvate) contents varied among the seven cultivars, although they were 5–13 times lower than the total soluble sugar contents. The Koshin cultivar showed the highest amylase activity, with a level approximately six times higher than that of the Sobutori cultivar, which had the lowest (Hara et al. 2009). Cultivars with higher amylase activities showed higher starch contents.

Anthocyanins

The anthocyanin concentrations of the mature radish taproot were significantly greater than in the sprouts of red, pink and purple varieties. The primary anthocyanidins present in the red and pink radish varieties were pelargonidin and delphinidin, while the primary anthocyanidin in the purple radish variety was cyanidin (Hanlon and Barnes 2011). Radish was reported to contain 7.40–128 mg/100 g pelargonidin anthocyanidins (Harnly et al. 2006; Wu et al. 2006). Two novel diacylated anthocyanins, pelargonidin 3-*O*-[2-*O*-(β-glucopyranosyl)-6-*O*-(*trans*-*p*-coumaroyl)-β-glucopyranoside] 5-*O*-(6-*O*-malonyl-β-glucopyranoside) and pelargonidin 3-*O*-[2-*O*-(β-glucopyranosyl)-6-*O*-(*trans*-feruloyl)-β-glucopyranoside] 5-*O*-(6-*O*-malonyl-β-glucopyranoside), were characterised from red radish (Guisti et al. 1998). Two other monoacylated anthocyanins were determined to be pelargonidin 3-*O*-[2-*O*-(β-glucopyranosyl)-6-*O*-(*trans*-*p*-coumaroyl)-β-D-glucopyranoside] 5-*O*-(β-glucopyranoside) and pelargonidin 3-*O*-[2-*O*-(β-glucopyranosyl)-6-*O*-(*trans*-feruloyl)-β-glucopyranoside] 5-*O*-(β-glucopyranoside). Twelve acylated anthocyanins were isolated from the red radish (Otsuki et al. 2002). Six of these were identified as pelargonidin 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-β-D-glucopyranosyl]-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-caffeoyl-2-*O*-(6-(*E*)-feruloyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside);

pelargonidin 3-*O*-[6-*O*-(*E*)-*p*-coumaroyl-2-*O*-(6-(*E*)-caffeoyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-(6-(E)-caffeoyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-*p*-coumaroyl-2-*O*-(6-(*E*)-feruloyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); and pelargonidin 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-(2-(*E*)-feruloyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside). Ten known acylated anthocyanins were isolated from red radish (Liu et al. 2008). The acylated anthocyanins are all based on pelargonidin 3-sophoroside-5-glucoside, acylated with caffeoyl, feruloyl or *p*-coumaroyl moieties. The anthocyanins were pelargonidin 3-*O*-[6-*O*-(*E*)-caffeoyl-2-*O*-β-D-glucopyranosyl]-(1→2)-β-D-glucopyranoside)-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-caffeoyl-2-*O*-(6-(*E*)-caffeoyl-β-D-glucopyranosyl]-(1→2)-β-D-glucopypranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-caffeoyl-2-*O*-(6-(*E*)-feruloyl-β-D-glucopyranosyl]-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-p-coumaroyl-2-*O*-β-D-glucopyranosyl]-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-p-coumaroyl -2-*O*-(6-(*E*)-caffeoyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-β-D-glucopyranosyl]-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-(6-(*E*)-caffeoyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-p-coumaroyl-2-*O*-(6-(*E*)-feruloyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); pelargonidin 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-(6-(E)-feruloyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside); and pelargonidin 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-(2-(*E*)-feruloyl-β-D-glucopyranosyl)-(1→2)-β-D-glucopyranoside]-5-*O*-(β-D-glucopyranoside).

Three new acylated pelargonidin 3-sophoroside-5-glucosides were isolated from the root peels, petioles and flowers of red radish, *Raphanus sativus* 'Cherry Mate', in addition to the five known anthocyanins, namely, pelargonidin 3-sophoroside-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(*trans-p*-coumaroyl)-glucoside]-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(*trans*-feruloyl)-glucoside]-5-glucoside, pelargonidin 3-[2-(glucosyl)-6-(*trans-p*-coumaroyl)-glucoside]-5-(6-malonylglucoside) and pelargonidin 3-[2-(glucosyl)-6-(*trans*-feruloyl)-glucoside]-5-(6-malonylglucoside) (Tatsuzawa et al. 2008). The structures of the three new acylated anthocyanins were shown to be pelargonidin 3-*O*-[2-*O*-(*β*-D-glucopyranosyl)-6-*O*-(*trans*-caffeoyl)-*β*-D-glucopyranoside]-5-*O*-(6-*O*-malonyl-*β*-D-glucopyranoside), its demalonyl derivative, and pelargonidin 3-*O*-[2-*O*-(*β*-D-glucopyranosyl)-6-*O*-(*cis-p*-coumaroyl)-*β*-D-glucopyranoside]-5-*O*-(6-*O*-malonyl-*β*-D-glucopyranoside). *p*-Coumaroyl anthocyanins were the main pigments found in the root, petioles and flowers. Although the *trans-p*-coumaroyl form was abundant in all three plant organs, its *cis* form was present in very low amount within the root but in large amount in the flowers and petioles. Four new acylated cyanidin glycosides were isolated from the purple roots of *Raphanus sativus* 'Benikanmi', along with five known anthocyanins (Tatsuzawa et al. 2010). Two of these pigments were determined to be cyanidin 3-*O*-[2-*O*-(β-glucopyranosyl)-6-*O*-(*trans*-feruloyl)-β-glucopyranoside]-5-*O*-[6-*O*-(malonyl)-β-glucopyranoside] and cyanidin 3-[2-(glucosyl)-6-(*cis-p*-coumaroyl)-glucoside]-5-[6-(malonyl)-glucoside]. Two other new pigments were obtained in small quantities and were assigned to be malonyl cyanidin 3-sophoroside-5-glucoside and malonyl cyanidin 3-[2-(glucosyl)-6-(*trans*-caffeoyl)-glucoside]-5-glucoside.

Six new acylated anthocyanins were isolated along with the three known congeners from the fresh roots of red radishes (Tamura et al. 2010). Their chemical structures were elucidated as 3-*O*-[6-*O*-(*E*)-caffeoyl-2-*O*-{6-*O*-(*E*)-caffeoyl-β-D-glucopyranosyl}-β-D-glucopyranosyl]-5-*O*-(6-*O*-malonyl-β-D-glucopyranosyl)pelargonidin; 3-*O*-[6-*O*-(*E*)-*p*-coumaroyl-2-*O*-{6-*O*-(*E*)-

caffeoyl-β-D-glucopyranosyl}-β-D-glucopyranosyl]-5-*O*-(6-*O*-malonyl-β-D-glucopyranosyl) pelargonidin;3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-{6-*O*-(*E*)-*p*-coumaroyl-β-D-glucopyranosyl}-β-D-glucopyranosyl]-5-*O*-β-D-lucopyranosylpelargonidin; 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-{6-*O*-(*E*)-caffeoyl-β-D-glucopyranosyl}-β-D-glucopyranosyl]-5-*O*-(6-*O*-malonyl-β-D-glucopyranosyl)pelargonidin; 3-*O*-[6-*O*-(*E*)-*p*-coumaroyl-2-*O*-{6-*O*-(*E*)-*p*-coumaroyl-β-D-glucopyranosyl}-β-D-glucopyranosyl]-5-*O*-(6-*O*-malonyl-β-D-glucopyranosyl) pelargonidin; and 3-*O*-[6-*O*-(*E*)-feruloyl-2-*O*-{6-*O*-(*E*)-*p*-coumaroyl-β-D-glucopyranosyl}-β-D-glucopyranosyl]-5-*O*-(6-*O*-malonyl-β-D-glucopyranosyl)pelargonidin. Sixty anthocyanins, 14 acylated cyanidin 3-(glucosylacyl) acylsophoroside-5-diglucosides, 24 acylated cyanidin 3-sophoroside-5-diglucosides and 22 acylated cyanidin 3-sophoroside-5-glucosides, were found in purple Bordeaux radish (Lin et al. 2011). The presence of 38 acylated cyanidin 3-sophoroside-5-diglucosides and around ten acylated cyanidin 3-sophoroside-5-malonylglucosides was found reported in *R. sativus* for the first time.

The light irradiation (fluorescence light, 5,000 lx; at 25 °C) indicated that the red radish extract (in which major anthocyanins were pelargonidin glycosides acylated with a combination of *p*-coumaric, ferulic or caffeic acids) was more stable at lower pH than at higher pH (Matsufuji et al. 2007). The HPLC analyses revealed that diacylated anthocyanins in the extract were more stable to light at pH 3 than monoacylated anthocyanins. No significant difference in degradation rates of acylated anthocyanins at pH 5 was observed, whereas anthocyanins acylated with *p*-coumaric or ferulic acids were more stable at pH 7 than ones with caffeic acids. The stability to heat (at 90–95 °C) showed a tendency similar to that for light. The degradation behaviour of red radish extract to H_2O_2 was almost the same to those of light and heat, depending on the pH. However, HPLC analyses revealed that the stability of individual acylated anthocyanins was independent of the pH. DPPH radical scavenging activity of all acylated anthocyanins was higher than those of pelargonidin and pelargonidin 3-glucoside. The activity of acylated anthocyanins mostly depended on the activity of intramolecular acyl units (caffeic acid > ferulic acid > *p*-coumaric acid). In another study, 17 pigments were tentatively identified as pelargonidin 3-sophoroside-5-glucoside derivatives with multiple acylation of hydroxycinnamic acids in the roots of Chinese radish cultivars (Jing et al. 2012). These Chinese radish cultivars showed high variation in anthocyanins (63.77–160.74 mg/100 g FW). A bright colour (CIELab) of radish anthocyanins was shown at a wide pH range, comparatively stable at pH < 4.2. Those anthocyanins also showed a remarkable thermal stability, following a zero-order kinetics at pH 2.5 with half-lives of 14.5 or 8.7 hours at 90 or 100 °C, respectively. Additionally, those cultivars varied in glucosinolate contents (59.69–163.91 mg/100 g FW), whereas their degradation was sensitive to pH and followed a first-order kinetics at pH 5.8 with half-lives of 11.44 or 7.05 hours at 90 or 100 °C, respectively. However, the stable pH ranges for anthocyanins and glucosinolates were different: pH < 4.2 and pH > 3.6, respectively. In a radish juice model (pH 5.8/2.5), thermal degradation of anthocyanins or glucosinolates was associated closely with media pH values.

Red radish anthocyanins (RRAs) in various fruit juice beverages (apple, grape, peach, pear, pomegranate and lemon) displayed a much faster degradation rate during storage at room temperature ($t_{1/2}$ value ≤84.0 days) than did in refrigerated temperature (Liu et al. 2014). During heating, RRAs in peach and pomegranate showed higher stability than others at these temperatures. There was a positive correlation ($R^2 > 0.9128$) between ascorbic acid content of juice beverages (8–36 mg/100 mg) and stability of RRAs at 70–90 °C. It was found that RRAs in apple and pear juice beverages were more stable than in other juice beverages.

Glucosinolates/Isothiocyanates/Nitriles

Intact roots of 109 radish cultivars including oil radishes (subsp. *oleifera*) and food radishes (subsp. *radicola*) from European, European-American, Japanese and Korean markets were found to contain primarily 4-methylthio-3-butenyl

glucosinolate (GS) with small amounts of 4-methylsulfinylbutyl GS, 4-methylsulfinyl-3-butenyl GS and 3-indolylmethyl GS (Carlson et al. 1985). Regarding total GSs, 80 % or more of the red European-American radishes had 100–199 μmole/100 g, the Korean 100–299 μmole/100 g and the Japanese 200–399 μmole/100 g. No correlation was found between root size and 4-methylthio-3-butenyl-, 3-indolylmethyl- or total GSs. Japanese radish peelings contained significantly greater concentrations of these three constituents than did the peeled root. Early radish (Rex and Ostergruss Różowa) contained the least amount of thiocyanate compounds and winter radish cv. Murzynka the highest amount (Capecka 1998). The content of thiocyanates in leaves was three to five times higher than that in hypocotyl roots in all cultivars including Japanese radish (Tokinashi and Minowase Summer Cross F1) and winter radish (Monachijska Biała and Murzynka). The changes in the thiocyanate content during root growth showed a constant rising tendency in the case of the leaves of all cultivars and the storage organs of Murzynka. Elivra and Tatiana (2012) reported radish to contain thioglycosides sinalbin, sinigrin and glucobrassicin. They found black radish to have higher content of isothiocyanates 37.6 mg/100 g versus green radish 33.7 mg/100 g and higher level of indole compounds 35.91 mg/100 versus 24.41 mg/100 g in green radish.

Trans-4-(methylthio)-3-butenyl glucosinolate (4MTBGLS) was isolated as a potassium salt from radish roots (Visentin et al. 1992). The contents of 4-methylthio-3-butenyl isothiocyanate (MTBITC) in more than half of the commercial Japanese radish cultivars ranged from 200 to 300 μmol/100 mL juice (Okano et al. 1990). Among the cultivars examined, 'Karami' showed the highest content of MTBITC, reaching as much as 1,735 μmol/100 mL, followed by the 'Shinshujidaikon' group of 400–700 μmol/100 mL. The 'Ninengo' and 'Shiroagari' groups also exhibited relatively high content averaging more than 300 μmol/100 mL. On the contrary, the 'Miyashige' group or Chinese cultivars contained the lowest level of MTBITC ranging from 100 to 200 μmol/100 mL. The result of sensory evaluation on grated radish showed that a cultivar with higher content of MTBITC was proportionately more pungent, supporting the notion that MTBITC was the pungent principle in roots of Japanese radish.

Studies by Ishii and Saijo (1987) found that isothiocyanate (ITC) in daikon roots decreased with days after sowing. The roots harvested in early summer contained a higher level of ITC than those harvested in autumn. ITC was higher in radish roots grown in alluvial soils. Mulching treatment with plastic film increased ITC in roots. ITC in the roots increased linearly with increasing sulfate levels in pots filled with vermiculite. Planting density did not affect ITC in roots. The range and mean of 4-methylthio-3-butenyl glucosinolate (MTBGLS) contents in 20 daikon cultivars were 42–345 μmo1/100 g of fresh weight and 210 μmol/100 g of fresh weight, respectively (Ishii et al. 1989b). Among the cultivars examined, the highest in total glucosinolate content contained 2.3 times higher than the lowest. The mean content of MTBGLS corresponded to about 80 % of that of total glucosinolate. 4-Methylthio-3-butenyl glucosinolate, the predominant glucosinolate in daikon root, was quantitatively determined after myrosinase enzymatic conversion to its isothiocyanate (Ishii et al. 1989a).

The major volatile components in the oil of the roots of black, white and red radish in respective sequence were hexadecanoic acid (palmitic acid) (32.2, 30.3, 49.9 %), methyl linolenate (21.7, 13.7, 8.5 %), 4-(methylthio)butyl isothiocyanate (erucin) (21.5, 25.7, 17.9 %), 5-(methylthio)-4-pentenenitrile (6.9, 5.3, tr%), dimethyl trisulfide (1.1, 1.3, 3.8 %), 5-(methylthio)pentyl isothiocyanate (berteroin) (0.5, 2.0, 0.6 %), 4-(methylthio)-3-butenyl isothiocyanate (0.2, 1.7, 0.7 %) and 2-phenylethyl isothiocyanate (1.0, 1.5, 0.1 %) (Blažević and Mastelić 2009). Other isothiocyanates and nitriles included 4-methylpentyl isothiocyanate (0.1, 0.1, 0 %), benzenepropanenitrile (tr, tr, 0 %), 3-(methylthio)propyl isothiocyanate (iberverin) (tr, 0.5, 0.7 %) and benzyl isothiocyanate (tr, 0.5, tr %). Alkanes identified in the roots were undecane (0.1, 0.3, tr%), dodecane (0,1.1,1.4 %), tridecane

(0.4, 0.5, 1.2 %), tetradecane (tr, 0, 0.7 %), heneicosane (0, 2.5, 0 %), tricosane (0, 2.3, 0 %) and tetracosane (0,1.2, 0 %). Other aliphatic alcohols and carbonyls identified in the roots were (*Z*)-3-hexen-1-ol (tr, 0.7, 0 %), (*E*,*E*)-2,4-heptadienal (0.1,0, 0.1 %), 2-phenylacetaldehyde (0.1, tr, 0 %), 4-ethylbenzaldehyde (0, tr, 0 %), 6,10,14-trimethyl-2-pentadecanone (0.1, 0, 0 %), isobutyl phthalate (0, 0.1, 0.3 %) and dibutyl phthalate (0.1, 0.7, 1.1 %). Other fatty acids and esters identified were (Z)-3-hexenyl acetate (tr, tr, tr%), dodecanoic acid (lauric acid) (tr, 0, o.5 %), benzyl benzoate (0.1,0,0 %), tetradecanoic acid (myristic acid) (1.9,0.5, 0 %) and pentadecanoic acid (0.2,0, 0 %). Other sulfur and/or nitrogen compounds identified were dimethyl disulfide (1.8, tr,1.3 %), 2-acetylthiazole (tr, 0, 0 %), 1-(methylthio)-3-pentanone (0.1, 0.3, 0 %) and dimethyl tetrasulfide (0, 0, 0.5 %). Terpenes identified were β-caryophyllene (tr, 0, tr) and neophytadiene (0.1, tr, 0 %). Miscellaneous compound identified included 4-vinyl-2-methoxyphenol (tr, 0, tr%).

Glucoraphasatin an atypical glucosinolate mainly found in *Raphanus sativus* roots and sprouts and its corresponding isothiocyanate, 4-methylsulfanyl-3-butenyl isothiocyanate, had been found to upregulate enzymes involved in the detoxification of carcinogens with the potential to be used as chemopreventive agents (Montaut et al. 2010). Six glucosinolates were identified and quantified in the black radish-based dietary supplements: glucoraphasatin (0.2–0.48 mg/g), glucosisaustricin (0.37–0.91 mg/g), glucoraphenin (0.84–1.27 mg/g), glucoputrajivin (0.14–0.28 mg/g), glucosisymbrin (0.70–0.99 mg/g) and gluconasturtiin (0.06–0.12 mg/g) (Ediage et al. 2011). Glucoraphenin was the most abundant glucosinolate in all samples.

Four radish glucosinolates (glucoraphenin, dehydroerucin, glucobrassicin and glucoerucin) were identified from root extracts, and dehydroerucin was found to be the major glucosinolate in red radish roots (Gao et al. 2014). Application of chitosan with 76 %, 83 % or 89 % deacetylation in radish extracts attributed to 26 %, 35 % or 43 % adsorption rate for glucosinolates and 28 %, 26 % or 22 % for anthocyanins, respectively. It was found that the concentration of volatile compounds decreased by 70 %, resulting in the loss of odorous compounds. The changes in chitosan spectra before/after adsorption and after desorption at 1,590 and 3,360 cm(−1) and at broad bands from 2,600 to 2,000 cm(−1) suggested that the dominant adsorption mechanisms of glucosinolates on chitosan may be electrostatic attractions, including hydrogen bonds and charge neutralisation.

The steam-volatile constituents of fresh radish of Japanese and Kenyan origin identified included 4-methylthio-3- butenyl isothiocyanate and its parent glucosinolate, dimethyl disulfide, methyl methanethiol sulfinate, pentyl isothiocyanate, 4-methylpentyl isothiocyanate, hexyl isothiocyanate, 5-(methylthio)-4-pentenenitrile, 3-methylthiopropyl isothiocyanate, benzyl isothiocyanate, 4-methylthiobutyl isothiocyanate, 5-methylthiopentyl isothiocyanate, (*E*)-2-hexenal, (*Z*)-3-hexenol, 1-methylthio-3-pentanone, 5-hexenyl isothiocyanate, 5-(methylthio)-pentane nitrile and 2-phenylethyl isothiocyanate (Kjaer et al. 1978).

The six heirloom Japanese radish varieties produced 2.0–11.5 times higher levels of 4-methylthio-3-butenyl isothiocyanate (MTBITC) as compared to the widely consumed conventional variety, Aokubi (Nakamura et al. 2008). The myrosinase, a cytosolic plant enzyme that hydrolyses 4-methylthio-3-butenyl glucosinolate (MTBGLS) into the natural pungent agent 4-methylthio-3-butenyl isothiocyanate (MTBITC), was located exclusively in the outer epidermal layer in Aokubi daikon, while 4-methylthio-3-butenyl glucosinolate (MTBGLS) was widely distributed throughout the root tissue. Despite the skin being a potentially rich source of myrosinase in Aokubi, the skin is usually peeled off in the current practice of preparing daikon for cooking. Thus, new practices were therefore proposed for the preparation of daikon tubers that eliminated the peeling of the skin to avoid removing the enzyme needed to convert MTBGLS to the health-beneficial MTBITC.

A total of eight glucosinolates were identified in different tissues of radish, including five aliphatic glucosinolates (4-methylsulfinyl-3-butenyl

glucosinolate, 2-hydroxy-3-butenyl glucosinolate, ethyl glucosinolate, 4-methylthio-3-butenyl glucosinolate and 6-heptenyl glucosinolate) and three indole glucosinolates (1-methoxyindol-3-ylmethyl glucosinolate, indol-3-ylmethyl glucosinolate, 4-hydroxyindol-3-ylmethyl glucosinolate) (Li et al. 2008). The contents of total glucosinolates in the edible roots and sprouts were higher than that in the leaves. The major glucosinolate in edible roots and sprouts was 4-methylthio-3-butenyl glucosinolate, accounting for 75.5 % and 71.5 % of the total glucosinolates, respectively. Indol-3-ylmethyl GS was the major glucosinolate in radish leaves, accounting for 57.1 % of the total leaf glucosinolates.

Other Phytochemicals

The contents of phenolic acids (hydroxycinnamic acids and hydroxybenzoic acids) in radish roots were much smaller than in the corresponding leaves (Stöhr and Herrmann 1975). In small radishes, *p*-coumaric acid and, in radishes, ferulic acid dominated after hydrolysis. Small radishes showed higher concentrations of phenolic acids in outer tissue layers. In contrary to hydroxycinnamic acid derivatives, the contents of hydroxybenzoic acid derivatives (*p*-hydroxybenzoic, vanillic, salicylic and gentisic acid) mostly were small. Partially, hydroxycoumarins (aesculetin and scopoletin) were also identified. *N*-methylphenethylamine, a secondary amine with indirect sympathomimetic action (Marquardt et al. 1976), and phenethylamine (Gutiérrez and Perez 2004) were found in radish root.

Alkaloids, saponins and flavonoids and the following constituents were detected in the swollen radish root: 11 long-chain alkyl esters, 3-methyl-5-propylnonane, 5-(hydroxymethyl)undecane, 4,6-dimethyldodecane, n-tetradecane; n-hexadecane, n-heneicosane; 2,6,10,14-tetramethylhexadecane; n-eicosane, methyl n-tetradecanoate; 2,6,10,15-tetramethylheptadecane; n-tricosane; n-hexadecanoic acid methyl ester; tritetracontane; 10-octadecenoic acid methyl ester; 9-octadecenoic acid ethyl ester; 2 aromatic ketones, diphenyl-benzophenone and 1-phenyl-pent-4-en-1-one; a benzyl halide, a-iodotoluene; an aryl ether, 1-methoxy-4-(prop-2-en-1-yl)benzene; a quinone, 2,6-di-tert-butylquinone; an aromatic aldehyde, 2-benzylideneoctanal; a long-chain aromatic alkane, 6-phenyldodecane; and a long-chain alkyl nitrile, 9-octadecenitrile (San Jaun et al. 2012).

The enzyme cysteine synthase comprising of two identical subunits of molecular weight 33,000 was isolated from radish roots (Tamura et al. 1976). Radish root was found to contain phospholipase D (Rakhimov et al. 1981). Phospholipase D displayed a more pronounced specificity for lecithin as substrate and was weakly active in the reaction with cephalin. An addition of Ca2+ increases the enzymatic affinity for the substrate in all cases studied. Two cationic isoperoxidases (designated C1 and C3) and four anionic isoperoxidases (designated A1, A2, A3n and A3) from Korean radish root were purified (Lee and Kim 1994). All six isoperoxidases were glycoproteins composed of a single polypeptide chain. The MW of C1, C3, A1 and A2 were ca 44,000, while anionic isoperoxidases A3n and A3 had MW of 31,000 and 50,000, respectively. Deglycosylated A2 and C3 by trifluoromethanesulfonic acid treatment showed MWs of 37,000 and 40,000, respectively, suggesting that the carbohydrate contents for these isoenzymes were 14 and 9 %, respectively. Two chitin-binding proteins with lysozyme activity, named as CBP1 and CBP2, were purified to homogeneity with the molecular weights of 26.9 kD and 24.8 kD, respectively, from radish roots (Lai et al. 2006). CBP1 and CBP2 were found to be bifunctional enzymes with activities of lysozyme and chitinase, but without chitosanase activity. A unique acidic calcium-binding protein RVCaB, rich in glutamic acid and proline and lacking aromatic amino acid residues, was found in radish vacuoles and may be involved in the vacuole Ca(2+) storage function (Ishijima et al. 2007). RVCaB was found to be predominantly an unstructured protein with a polyproline type II helix.

Arabinogalactan proteins (AGPs) were isolated from primary and mature radish roots (Tsumuraya et al. 1988). These root AGPs were composed mainly of L-arabinose and D-galactose but were distinguishable from each other in their contents of L-fucose as well as of protein and hydroxyproline. The structures of the carbohy-

drate moieties of the root AGPs were essentially similar to those of AGPs isolated from seeds and mature leaves in that they consisted of consecutive (1→3)-linked β-D-galactosyl backbone chains having side chains of (1→6)-linked β-D-galactosyl residues, to which α-L-arabinofuranosyl residues were attached in the outer regions. Three ferredoxin isoproteins (R-Fd A, R-Fd B-1 and R-Fd B-2) were purified from white roots of radish (*Raphanus sativus* L. var. *acantiformis* cultivar Miyashige) (Wada et al. 1989). 1-*O*-sinapoyl-β-glucose:L-malate *O*-sinapoyltransferase (SMT) from cotyledons of red radish was purified to apparent homogeneity with a 2,100-fold enrichment and a 4 % recovery (Gräwe et al. 1992). Apparent molecular mass of 52 and 51, respectively, were determined. On isoelectric focusing, the SMT resolved into two isoforms which showed slightly different molecular mass (SMT I, Mr/isoelectric point = 51/5.75; SMT II, Mr/isoelectric point = 51.5/5.9). The enzyme accepted all the hydroxycinnamic acid glucose esters tested with relative ratios of initial velocity values of 100 : 85 : 45 : 26 : 2.6 of 1-*O*-sinapoyl-, 1-*O*-feruloyl-, 1-*O*-caffeoyl-, 1,2-di-*O*-sinapoyl- and 1-*O*-(4-coumaroyl)-β-glucose.

Genes involved in anthocyanin biosynthesis in radish include phenylalanine ammonia lyase (PAL), cinnamate 4-hydroxylase (C4H), 4-coumarate-CoA ligase (4CL), chalcone synthase (CHS), chalcone isomerase (CHI), flavanone 3-hydroxylase (F3H), dihydroflavonol reductase (DFR) and anthocyanidin synthase (ANS). RsDFR and RsANS were found to accumulate in the flesh or skin of two radish cultivars (Man Tang Hong and Hong Feng No. 1) (Park et al. 2011). Radish skin contained higher CHS, CHI and F3H transcript levels than radish flesh in all three cultivars. In red radish, 16 anthocyanins were separated and identified. Some of them were acylated with coumaroyl, malonyl, feruloyl and caffeoyl moieties. Furthermore, (-)-epicatechin and ferulic acid were also identified in the three cultivars.

Myrosinase was found to accumulate in myrosin cells and in other non-specialised cells in the seeds, seedling and other organs of radish plant (Phelan et al. 1984). Two myrosinase isoenzymes were extracted and purified from radish root tissues with M_rs 28,800 and 58,900 (Jwanny et al. 1995). The most active one (120 U/mg) was identified and characterised. The yield of the purified myrosinases was 21 mg (2,398 U) of pure enzymes from 100 g of dry root tissues. Myrosinase (thioglucoside glucohydrolase), a plant enzyme that hydrolyses glucosinolates, principally to isothiocyanates, was purified to homogeneity in good yield from 8-day-old daikon seedlings (Shikita et al. 1999). The purified enzyme was resolved into two subunits with molecular masses of 61 and 62 kDa. Ascorbic acid activated the purified enzyme more than 100-fold. The enzyme also had β-glucosidase activity and hydrolysed *p*-nitrophenyl-β-D-glucopyranoside. Two myrosinase isoenzymes were extracted and purified from radish root tissues with M_rs 28,800 and 58,900 (Jwanny et al. 1995). The most active one (120 U/mg) was identified and characterised. The yield of the purified myrosinases was 21 mg (2,398 U) of pure enzymes from 100 g of dry root tissues. Two cDNA clones of myrosinase (thioglucoside glucohydrolase) were isolated from radish (*Raphanus sativus*) seedlings (Hara et al. 2000). Both clones were identified as MB (B type myrosinase). The tissue distribution of gene expression and enzyme activity of myrosinase corresponded well to the site of glucosinolate accumulation in different tissues of radish. The myrosinase–glucosinolate system was localised in the cotyledons in the seedlings and in the peel of the root in the mature plant. Myrosinase mRNA and activity were localised in the epidermis and vascular cambium that were present in the peripheral part of the root, but few signals were detected in the parenchyma inside of the vascular cambium. Since the myrosinase–glucosinolate system is known to be a defence system in higher plants, the localisation of the myrosinase–glucosinolate system in the peel of the root may act to protect the sink organ from the attack of herbivores or pathogens in soil.

In radish, the concentrations of individual polycyclic aromatic hydrocarbons (PAHs) and phthalic acid esters (PAEs) varied from

undetectable to 803 μg/kg dry weight (DW) and from undetectable to 2,048 μgkg DW, respectively (Cai et al. 2008). Compared to the control, higher application rates of sewage sludge resulted in pronounced increases in radish shoot, root and soil concentrations of PAHs and PAEs. PAE concentrations in radish grown in latosolic red soil spiked with sludge compost were higher, while the PAH concentrations were comparable to those receiving 10 g/kg of sewage sludge. However, the root biomass of radish in soil amended with compost was significantly higher, and the shoot-to-root ratio was significantly lower than in the other treatments. The bioconcentration factors (BCFs, the ratio of contaminant concentration in plant tissue to the soil concentration) of di-n-butyl phthalate and di(2-ethylhexyl) phthalate in both shoots and roots and of total PAH concentrations in roots were less than 1.0, but some BCFs for individual PAHs were high with a maximum value of 80.

Phytochemicals in Leaf/Stem

In radish leaves, the anaerobic accumulation of alanine was accompanied by a loss of aspartate, and these changes preceded gamma-aminobutyrate accumulation and glutamate loss (Streeter and Thompson 1972). Accumulation of gamma-aminobutyrate was due to acceleration of glutamate decarboxylation and arrest of gamma-aminobutyrate transamination. Changes in keto acid content did not appear to be the cause of amino acid changes. Most of the aspartate may be converted anaerobically to alanine via oxaloacetate and pyruvate. Regarding phenolic acids (hydroxycinnamic acid compounds), leaves of radish (*Raphanus sativus* var. *sativus* and var. *nige*r) mainly contained compounds of caffeic and *p*-coumaric acid (Schmidtlein and Herrmann 1975). In the group of hydroxybenzoic acid derivatives, traces of salicylic and gentisic acid and frequently vanillic acid were also found. Caffeic, *p*-coumaric,, ferulic and sinapic acid esters of malic acid and the enzyme(s) involved in their syntheses were found in the vacuoles of radish leaf protoplasts (Strack and Sharma 1985). The flavonoid kaempferol 3,7-di-*O*-a-L-rhamnopyranoside (lespedin) was identified in radish leaves (Muminova et al. 2006). The following polyphenolic compounds catechin, protocatechuic acid, syringic acid, vanillic acid, ferulic acid, sinapic acid, *o*-coumaric acid, myricetin, and quercetin were found in radish leaves and stem (Beevi et al. 2010b). Oriental radish (Longipinnatus group) was reported to contain the flavonol kaempferol 0.34 mg/100 g (Arai et al. 2000). Quercetin, rutin and kaempferol were determined in radish leaves by liquid chromatography–tandem mass spectrometry (Devaraj et al. 2011).

Radish leaf was characterised chiefly by indole glucosinolates, largely 3-indolylmethyl-glucosinolate (glucobrassicin) with traces of 4-methoxy-3-indolylmethyl-glucosinolate (4-methoxyglucobrassicin) and 4-hydroxy-3-indolylmethyl-glucosinolate (4-hydroxybrassicin) (Sang et al. 1984). Hydroxylated cinnamic acid malate esters, namely, 2-*O*-(*p*-coumaroyl)-L-malate, 2-*O*-caffeoyl-L-malate and 2-*O*-feruloyl-L-malate, were found to be quantitatively predominating compounds in the fraction of carboxylic acids isolated from radish leaves and inflorescences (Nielsen et al. 1984). The esters of *p*-coumaric, ferulic and caffeic acid with malic acid were isolated from the leaves, the ester of sinapic acid with malic acid from cotyledons of *R. sativus* (Brandl et al. 1984). The flavonoid kaempferol 3,7-di-*O*-α-L-rhamnopyranoside (lespedin) was isolated from radish leaves (Muminova et al. 2006).

The major volatile components found in the oil of leaves of black, white and red radish in respective sequence were phytol (65.3, 69.7, 65.9 %), hexadecanoic acid (palmitic acid) (14.3, 2.5, 8.5 %), methyl linolenate (11.1, 8.9, 2.1 %) and (*Z*)-3-hexen-1-ol (0.7, 0.7, 6.9 %) (Blažević and Mastelić 2009). Corresponding aliphatic or aromatic glucosinolate compounds identified in the leaves constituted only 0.3–5.7 % of the isolated volatiles. They were 4-methylpentyl isothiocyanate (0, 0.1, 0 %), 5-(methylthio)-4-pentenenitrile (tr, 2.2, 0.3 %), 4-(methylthio)butyl isothiocyanate erucin (0.3,1.7, tr %), 2-phenylethyl isothiocyanate (tr,

0.4, 0 %), 4-(methylthio)-3-butenyl isothiocyanate (0, tr, 0 %), benzenepropanenitrile (0, tr, 0 %), 3-(methylthio)propyl isothiocyanate (iberverin) (0, tr, 0 %), benzyl isothiocyanate (tr, 0, 0 %) and 2-phenylethyl isothiocyanate (tr, 0.4, 0 %). Alkanes identified in the leaves were undecane (tr, 0.2, 0.2 %), dodecane (0.3, 1.1, 0.8 %), tridecane (0.1, 0.3, 0.3 %), tetradecane (tr, tr, 0.1 %), tricosane (0.2, 0.3, 0.5 %) and tetracosane (0.1,0.2,0.2 %). Other aliphatic alcohols and carbonyls identified in the leaves were (*E*)-2-hexenal (tr, tr, 0.8 %), nonanal (0, tr, 0.2 %), (*E*,*E*)-2,4-heptadienal (0.1,0, 0 %), benzaldehyde (tr, 0, 0 %), 2-phenylacetaldehyde (tr, 0.2, 0.2 %), 4-ethylbenzaldehyde (0, 0, 0.1 %), isobutyl phthalate (0, 0.3, 0 %) and dibutyl phthalate (0.4, 1.1, 1.0 %). Other fatty acids and esters identified were tetradecanoic acid (myristic acid) (tr, 0, 0 %) and methyl palmitate (0.1, 0, 0 %). Other sulfur and/or nitrogen compounds identified were dimethyl trisulfide (tr, 0.4, 0.2 %) and 1-(methylthio)-0-3-pentanone (0, tr, 1.1 %). Besides phytol, terpenes identified were (*E*)-β-ionone (0.5, 1.3, 1.4 %) and neophytadiene (1.5, 1.1, 1.3 %). Miscellaneous compound identified included 4-vinyl-2-methoxyphenol (0.5, 1.3, 1.0 %), 2,3-dihydrobenzofuran (coumaran) (0.1, tr, 0.4 %), β-cyclocitral (0, tr, tr), β-damascone (0, 0.1, 0 %) and 1H-indole (0.1, 1.8, 0.2 %). Nineteen volatile aglycones were identified for the first time in the leaves of all three varieties of radish. The main aglycones in the leaves of black, white and red radish were, respectively, eugenol (29.2, 30.2, 37.1 %), 2-phenylethanol (23.5, 2.0, 11.8 %), 4-vinyl-2-methoxyphenol (2.7, 12.4, 2.4 %), (*Z*)-3-hexen-1-ol (6.2, 2.6,10.4 %), methyl vanillate (0, 10.0, 6.3 %), 1H-indole (6.8, 2.2, 0.7 %), benzyl alcohol (4.2, 1.4, 1.8 %), vanillin (3.7, 3.5, 6.3 %) and methyl salicylate (3.4, 0.8, 0 %). Other aglycones included benzaldehyde (0.1, 1.4, 0 %), 2-phenylacetaldehyde (0, 0.9, 0 %), 1-phenylethyl alcohol (0.2, 0.1, 0.2 %), 2-methoxyphenol (guaiacol) (0.6, 1.7, 0 %), 2-methoxy-4-methylphenol (0, 2.2, 0 %), phenol (0, 2.3, 0 %), 4-ethyl-2-methoxyphenol (2.6, 2.3, 0 %), 2,4-dimethylphenol (0, 3.2, 0.3 %), 4-keto-α-ionol (0.5, 2.9, 2.1 %) and 3-hydroxy-β-ionone (0, 2.4, 1.1 %).

Two isoproteins (L-Fd A and L-Fd B) were isolated from radish leaves (Wada et al. 1989).

Three ferredoxin components, a, b and c, were found in the green shoots of Japanese radish seedlings and mature leaves (Obata et al. 1995). Component a was further separated into two components, a1 and a2. They found that the primary structures of components a1, a2 and b were all found in 12 possible structures of L-Fd A, one the two leaf ferredoxins, L-Fds A and B, isolated by Wada et al. (1989). They concluded that L-Fd A was a mixture of three ferredoxins corresponding to components a1, a2 and b.

Two L-arabino-D-galactan-containing glycoproteins having a potent inhibitory activity against eel anti-H agglutinin were isolated from mature radish leaves and characterised to have a similar monosaccharide composition that consisted of L-arabinose, D-galactose, L-fucose, 4-*O*-methyl-D-glucuronic acid and D-glucuronic acid residues (Tsumuraya et al. 1984). Two isoproteins (L-Fd A and L-Fd B) were isolated from (*Raphanus sativus* L. var. *acantiformis* cultivar Miyashige) leaves (Wada et al. 1989). Two induced radish leaf proteins (designated Rs-AFP3 and Rs-AFP4) were purified and shown to be homologous to seed Rs-AFPs and to exert similar antifungal activity in-vitro (Terras et al. 1995). A chimeric Rs-AFP2 gene under the control of the constitutive cauliflower mosaic virus 35S promoter conferred enhanced resistance to the foliar pathogen *Alternaria longipes* in transgenic tobacco. The term 'plant defensins' was proposed to denote these defence-related proteins. On the basis of molecular weight and their antifungal properties, the protein samples from the *Alternaria alternata*- and *Fusarium oxysporum*-infected radish leaves were found to be PR2 (glucanase) and PR3 (chitinase) (Khanal et al. 2014).

Gibberellins (GA_1, GA_3, GA_7) were reported to play a direct role in the bolting of 'Miyashige-sofuto' radish but were probably not directly functional in initiating flowering (Suge and Rappaport 1968). The concentrations of putative active GAs (GA_1 and GA_4) and their precursors (GA_9 and GA_{20}) in both the stems and leaves of *R. sativus* grown without cold treatment were higher in the long-day condition than the short-day

condition (Nakayama et al. 1995). The concentrations of the above four GAs in the stems and leaves generally tended to decrease during the cold treatment, although GA_1 in the stems was at almost the same level before and after the cold treatment. These results suggested that the GA biosynthesis was promoted by the long-day condition rather than cold treatment. Considering that application of GAs after the cold treatment as well as cultivation in the long-day condition after cold treatment induced the bolting of *R. sativus*, both the cold treatment and activation of GA biosynthesis by cultivation in the long-day condition appeared to be essential to bolting. A series of GAs belonging to either the early-13-hydroxylation or early-non-hydroxylation pathway were identified in four cultivars of Japanese radish (*Raphanus sativus* L. cvs. Sofutori-Miyashige, Wakayama, Hanashirazu-Hayafutori-Tokinashi and Wase-Shijunichi), which varied greatly in their cold requirement for bolting (or stem elongation) and flowering, suggesting that the endogenous active GAs were GA_1 and GA_4 (Nishijima et al. 1995). The concentration of GA_1 increased in the stem and decreased in the leaf during bolting in all the cultivars.

Two anti-migraine compounds were isolated from radish roots and elucidated as *cis*-(1-methylazetidin-2-yl)methanol and cyclo-(4-methyl-val-4-methyl-val) (Wu et al. 2014).

Foliar applications of brassinosteroids (polyhydroxyl steroidal phytohormones), namely, 28-homobrassinolide and 24-epibrassinolide, to the radish plants resulted in substantial increment (65 %) in soluble protein contents and nucleic acids DNA and RNA (Vardhini et al. 2012). Increased levels of carbohydrates in terms of reducing sugars, nonreducing sugars and starch were also observed.

Seed Phytochemicals

The major active compounds in radish seeds reported were alkaloids, glucosinolates, brassinosteroids and flavonoids (Sham et al. 2013). Two fructooligosaccharides, sucrose, glucose and galactose were identified in radish and *Brassica napus* seed ethanol extracts (Orlovskaya et al. 2013).

The thiocyanate (SCN)− content in radish seeds prior to planting was negatively correlated with the SCN− content in marketable roots of five white cultivars (Chong and Bible 1975). On the contrary, there was a corresponding positive correlation for eight red cultivars. Although larger seeds resulted in larger radishes, there was no difference in SCN− content in the root of plants grown from different seed sizes. Studies by Sang et al. (1984) found that the only indole glucosinolate present in the radish seed meal was 4-hydroxy-3-indolylmethyl GS (4-hydroxyglucobrassicin) with the dominant glucosinolate being 4-methylsulfinylbut-3-enyl GS (glucoraphenin), which contained an unsaturated sulfinyl R group. Ten isothiocyanates, seven aliphatic hydrocarbons and some other volatile substances were characterised in *Raphanus sativus* var. *niger* seeds (Afsharypuor and Balam (2005). The main isothiocyanates were hexyl isothiocyanate (18.4 %), 4-methylthiobutyl isothiocyanate (17 %), 4-methylpentyl isothiocyanate (8.4 %), 4-methylthio-(3*E*)-butenyl isothiocyanate (5.2 %), 4-methylthio-(3*Z*)-butenyl isothiocyanate (4.7 %) and isoamyl isothiocyanate (2.4 %). Seven 4-methylthio-butanyl derivatives were identified in the radish seed methanol extract: sinapoyl desulfoglucoraphenin, (*E*)-5-(methylsulfinyl)pent-4-enoxylimidic acid methyl ester, (*S*)-5-((methylsulfinyl)methyl)pyrrolidine-2-thione, 5-(methylsulfinyl)-4-pentenenitrile, 5-(methylsulfinyl)-pentanenitrile, sulforaphene and sulforaphane (Kim et al. 2014).

Radish seeds contained two major types of storage protein aggregates which could be separated by gel filtration into 12 and 1.7 Svedberg fractions (Laroche et al. 1984). Radish 12 Svedberg particles comprised a series of nine major polypeptides ranging from 33 to 30 kDa and composed of six subunits approximately 55 kDa. Each subunit is a couple of two polypeptides linked by a disulfide bridge. The 1.7 Svedberg particle is composed of two polypeptides of 10 and 12 kDa and smaller peptides of approximately 7 kDa. Twelve and 1.7 Svedberg particles also differed in their amino

acid composition, the 1.7 Svedberg being particularly rich in glutamic acid and proline. An L-arabino-D-galactan and an L-arabino-D-galactan-containing proteoglycan were isolated from radish seeds (Tsumuraya et al. 1987). The proteoglycan consisted of 86 % of a polysaccharide component containing β-L-arabinose and D-galactose as major sugar constituents, together with small proportions of D-xylose, D-glucose and uronic acids and 9 % of a hydroxyproline-containing protein. Raphanuside, an unusual oxathiane-fused thioglycoside isolated from *Raphanus sativus* seeds, was synthesised giving 11 % overall yield (Yang et al. 2010). Two novel sulfur compounds *S*-6-(methylsulfinyl)methyl-1,3-thiazinan-2-thione and *O*-ethyl *N*-(*E*)-4-(methylsulfinyl)but-3-enylcarbamothioate were isolated from the seeds (Zhang et al. 2010). A novel compound rasatiol was isolated from radish seed used as Korean herbal medicine, 'NaBokJa' (Roh et al. 2013).

A basic β-galactosidase (β-Galase) with an apparent molecular mass of 45 kDa was purified 281-fold from imbibed radish seeds (Sekimata et al. 1989). The enzyme was maximally active at pH 4.0 on *p*-nitrophenyl β-D-galactoside and β-1,3-linked galactobiose. Radish seed and leaf arabino-3,6-galactan proteins were resistant to β-Galase alone but could be partially degraded by the enzyme after the treatment with a fungal α-L-arabinofuranosidase leaving some oligosaccharides consisting of D-galactose, uronic acid, L-arabinose and other minor sugar components besides D-galactose as the main product. α-L-arabinofuranosidase was purified 1,043-fold from radish seeds (Hata et al. 1992). The purified enzyme was a homogeneous glycoprotein consisting of a single polypeptide with an apparent molecular weight of 64,000 and an isoelectric point value of 4.7. The enzyme characteristically catalyses the hydrolysis of *p*-nitrophenyl α-L-arabinofuranoside and *p*-nitrophenyl β-D-xylopyranoside. The enzyme was shown to split off α-L-arabinofuranosyl residues in sugar beet arabinan, soybean arabinan-4-galactan and radish seed and leaf arabinogalactan proteins. Arabinose and xylose were released by the action of the enzyme on oat-spelt xylan. Synergistic action of α-L-arabinofuranosidase and β-D-galactosidase on radish seed arabinogalactan protein resulted in the extensive degradation of the carbohydrate moiety. Radish seeds were found to contain two homologous, small, 5 kD, cysteine-rich oligomeric proteins designated *Raphanus sativus* antifungal protein 1 (Rs-AFP1) and Rs-AFP2; they were found in the cell wall occurring predominantly in the outer cell layers lining different seed organs (Terras et al. 1992a, 1995). The radish 2S storage albumins in the seeds were identified as the second novel class of antifungal proteins. An α-L-arabinofuranosidase/β-D-xylosidase was cloned from immature seeds of radish by reverse transcriptase-PCR (Kotake et al. 2006). It hydrolysed α-L-arabinofuranosyl residues of the carbohydrate moieties of arabinogalactan proteins (AGPs). The gene, designated RsAraf1, was found to encode a bifunctional α-L-arabinofuranosidase/β-D-xylosidase and the results suggested that RsAraf1 was involved in the hydrolysis of the carbohydrate moieties of AGPs in immature radish seeds. *Raphanus sativus* antifungal protein 1 (Rs-AFP1), a 51 amino acid residue plant defensin, was isolated from radish seeds (Fant et al. 1998). Cationic peroxidase Cs with molecular mass of 44 kDa was purified to apparent homogeneity and characterised from Korean radish seeds (Kim and Lee 2005). The cationic peroxidase Cs showed the peroxidase activities for native substrates, such as coumaric acid, ferulic acid and scopoletin. This result suggested that cationic peroxidase Cs may play an important role in plant cell wall formation during seed germination. Rs-AFP2 (*Raphanus sativus* antifungal peptide 2), an antifungal plant defensin, was isolated from radish seed (Aerts et al. 2007). Karri and Bharadwaja (2013) linked two plant defensins, namely, *Trigonella foenum-graecum* defensin 2 (Tfgd2) and *Raphanus sativus* antifungal protein 2 (Rs-AFP2) genes, by a linker peptide sequence (occurring in the seeds of *Impatiens balsamina*) and made into a single-fusion gene construct with enhanced antifungal activity.

Eleven gibberellins (GAs) were identified in extracts of mature seed of radish (*Raphanus*

sativus cv. Taibyosobutori) (Nakayama et al. 1990). These GAs comprised seven 13-hydroxy GAs [GA_1, 3-*epi*-GA_1, GA_8, GA_{17}, GA_{19}, GA_{20} and a new GA, 12α-hydroxy GA_{20} (GA_{77})] and four non-13-hydroxy GAs [GA_9, GA_{24}, 12β-hydroxy GA_{24} (tentative) and GA_{25}]. The major GAs were GA_8, GA_{20}, GA_{24} and GA_{77}.

During the first 48 hours after imbibition of water by quiescent radish seeds, the changes in ATP concentrations, oxygen utilisation and fresh weights followed a triphasic time course, characterised by a rapid initial increase, which extended from 0 to approximately 1.5 hours, a lag phase from 1.5 to 16 hours and a sharp linear increase from 16 to 48 hours (Moreland et al. 1974). After imbibition of water by the quiescent seeds, for 1 hour, the ATP concentration had increased to 2.5, and ADP and AMP concentrations had decreased to 0.3 and 0.1 nmole/seed, respectively. In unimbibed seeds, the concentrations of ATP, ADP and AMP were <0.1, 0.9, and 2.2 nmoles/seed, respectively. Oxidative phosphorylation was estimated to have contributed 15, 20 and 65 % of the pool ATP at 1.5, 16 and 48 hours, respectively.

Phytochemicals in Seedlings and Sprouts

In dark-grown radish seedlings, the level of phenylalanine transaminase was higher in cotyledons than in the root and hypocotyls (Tomè et al. 1975). The maximum activity of phenylalanine ammonia lyase (PAL) was found in the root. Only PAL was significantly increased by light. Continuous far-red light (active phytochrome P fr) stimulated the synthesis of all prenyl chains (C40 carotenoids; C45 in plastoquinone-9; C20 phytyl in chlorophylls, α-tocopherol and vitamin K1) in plastids of etiolated radish seedlings but had no or only little effect on the dark pattern of the prenyl chain formation (Lichtenthaler and Becker 1975). White light enhanced the accumulation of prenyl chains to a much higher degree than does far-red light. Two separate enzyme activities for the formation of the 7- and 9-glucopyranosyl derivatives of the cytokinin 6-benzylaminopurine (BAP) were found in soluble extracts of expanded cotyledons of radish and purified (Entsch and Letham 1979). Each activity resulted in the formation of both glucosides, and the enzymes use UDP-glucose as the source of the glucose residue.

Nucleoside polyphosphates, namely, nucleoside triphosphates, nucleoside tetraphosphates, pentaphosphates and hexaphosphates were found in labelled RNA preparations from radish seedlings (Aspart-Pascot et al. 1976). Polyadenylic and polyadenylated ribonucleic acids were found in radish seedlings (Aspart et al. 1979). Two lifetime classes of polyadenylic acid were determined in these seedlings: a short-lived component with a half-life of 30 minutes which represented 60 % of poly(A) and a more stable component with varying half-lives of which the majority range from 4 to 10 hours and a few were considerably longer. Anti-bolting activity was detected in an extract of rosette shoots of radish plants by an assay using seedlings cultured in-vitro (Yoshida et al. 2010). The causal compound that strongly inhibited bolting was isolated and identified as α-(7*Z*,10*Z*,13*Z*)-hexadecatrienoic acid monoglyceride (16:3 monoglyceride). The compound disappeared completely after vernalisation, and bolting occurred thereafter. A membrane-bound 3-hydroxy-3-methylglutaryl-coenzyme A reductase was characterised from 4-day-old, dark-grown radish seedlings (Bach et al. 1986).

The specificity of binding and the complete precipitation of β-fructosidase activity by the insolubilised lectin implied that all β-fructosidase activity measured in *Raphanus sativus* seedling extracts was linked to (a) glycoprotein form(s) of this enzyme (Faye and Berjonneau 1979). When 36-hour-old dark-grown radish seedlings were transferred to far-red light, there was a decrease in glycoprotein cytoplasmic β-fructosidase (betaF) and an increase in cell wall betaF compared to the dark controls (Faye et al. 1986). Cytoplasmic and cell wall-bound β-fructosidase exhibited high antigenic similarities but differed according to charge heterogeneity and carbohydrate microheterogeneity. Growth of radish seedlings in the presence of tunicamycin resulted in a partial inhibition of betaF glycosylation, but non-glycosylated betaF still accumulated in the cell

wall under far-red light. The nonglycosylated cytoplasmic and cell wall betaF forms have the same relative molecular mass, but glycosylated forms had different oligosaccharide side chains, with respect to size and susceptibility to α-mannosidase and endoglycosidase D digestion. An inhibitor of Ca^{2+}–calmodulin (Cam)-dependent brain phosphodiesterase was present in the soluble fraction of embryo axes from ungerminated radish seeds (Cocucci and Negrini 1988). During the early phases of germination, the fresh weight and the levels of DNA and RNA of embryo axes increased, the level of the inhibitor decreased and the level of Cam increased. It was found that the Ca^{2+}–calmodulin system was activated in early germination of radish seeds by an increase in Cam and a decrease in the inhibitor levels; that fusicoccin, probably through the activation of membrane functions, increased Cam level; and that the abscisic acid (ABA) inhibition on germination was not mediated by the Ca^{2+}–Cam system. The peptide-N4-(N-acetyl-β-D-glucosaminyl) asparagine amidase (PNGase) activity was found in dry radish seeds, and its level was constant during germination and post-germination (Berger et al. 1995). The endo-*N*-acetyl-beta-D-glucosaminidase (ENGase) activity was first detected about 18 hours after the start of imbibition (HAI) and displayed a maximum level at 36 HAI. After 36 HAI, the production of both enzymes was constant until days 4–5. Both enzymes displayed substrate specificities corresponding to the potential glycoprotein substrates found in plants.

In radish hypocotyl, 4-hydroxy-3-indolylmethyl glucosinolate (4-hydroxybrassicin), 4-methoxy-3-indolylmethyl glucosinolate (4-methoxyglucobrassicin) and 3-indolylmethyl glucosinolate (glucobrassicin) were present with the major glucosinolate being 4-methylthio-3-butenyl glucosinolate (glucoraphasatin) (Sang et al. 1984). In comparison to daikon seeds, glucoraphenin (4-methylsulfinyl-3-butenyl Gs, GRE) content in daikon sprouts decreased from about 90 to about 12 μmol/g of dry weight (DW), whereas a 25-fold increase from about 3 to 76 μmol/g DW of the glucoraphasatin (4-methylthio-3-butenyl Gs, GRH) content was determined (Barillari et al. 2005). An efficient pure GRH gram-scale production process from *R. sativus* (kaiware daikon) sprouts resulted in significant yield improvement of up to 2.2 % (DW basis). Radish sprouts contained significantly greater concentrations of glucosinolates (3.8-fold) and isothiocyanates (8.2-fold) than the mature radish taproot and also contained significantly greater concentrations of phenolics on average 6.9-fold (Hanlon and Barnes 2011).

Malate, which plays many essential roles in plant metabolism, was found to be a potent in-vitro inhibitor of the cytosolic enzyme phosphoenolpyruvate carboxylase in radish root hair cytoplasm (Bodson et al. 1991). A novel α-L-fucosyltransferase capable of transferring L-fucose (L-Fuc) from GDP-L-Fuc to the *O*-2 of α-L-arabinofuranosyl residue (GDP-L-Fuc–α-L-arabinofuranoside 2-α-L-fucosyltransferase) was found in the microsomal fraction of primary roots from 6-day-old radish seedlings (Misawa et al. 1996). Soluble and cell wall-bound gamma-glutamyl transferases (GGTs) were purified from radish cotyledons (Nakano et al. 2006). Soluble GGTs (GGT I and II) had the same M(r) of 63,000, and were composed of a heavy subunit (M(r), 42,000) and a light one (M(r), 21,000). The properties of GGT I and II were similar. Both soluble and bound GGTs utilised glutathione, gamma-L-glutamyl-p-nitroanilide, oxidised glutathione and the conjugate of glutathione with monobromobimane as substrates and were inhibited by acivicin, but soluble GGTs were also distinguished from bound GGTs with regard to these properties. Two forms of RD21 (responsive to desiccation-21), an Arabidopsis cysteine protease, were identified from cotyledons of daikon radish, consisting of an intermediate form (iRD21) containing a granulin domain and a mature form (mRD21) lacking this domain (Kikuchi et al. 2008). A cathepsin B-like cysteine protease (CBCP) that was reported to play a role in disease resistance and in protein remobilisation during germination was purified from daikon radish cotyledons (Tsuji et al. 2008). The molecular mass of the enzyme was estimated to be 28 kDa. The best synthetic substrate for CBCP was t-butyloxycarbonyl Leu-Arg-Arg-4-

methylcoumaryl 7-amide. Daikon CBCP exhibited both endopeptidase and exopeptidase activities. In addition, CBCP was found to display carboxymonopeptidase activity against the substrate o-aminobenzoyl-Phe-Arg-Phe(4-NO(2)).

Three acidic and three neutral growth inhibitors were detected in Sakurajima radish hypocotyls grown in light (Hasegawa and Miyamoto 1978). Among them, all of the acidic and one of the neutral inhibitors increased with the time period of illumination, whereas the other two neutral substances remained almost unchanged in the light but decreased in the dark. Thus, the levels of all six inhibitors were higher in light-grown seedlings than in dark-grown ones. A neutral growth inhibitor named raphanusol A was isolated as a colourless powder from light-grown radish seedlings and partially characterised as a phenolic compound (Hasegawa and Miyamoto 1980). Raphanusol A, isolated from an acetone extract of light-exposed seedlings of Sakurajima radish, was characterised as 1-β,4-di-*O*-(4-hydroxy-3,5-dimethoxycinnamoyl) gentiobiose (Hase and Hasegawa 1982). Another growth inhibitor, designated raphanusol B, was isolated in crystalline form from light-grown Sakurajima radish seedlings and has been shown to be 1-sinapoylglucose (Hasegawa and Hase 1981). Raphanusol B inhibited the growth of intact and excised hypocotyls of etiolated radish seedlings. The raphanusol B content of the radish seedlings increased greatly under red light but decreased in the dark. Another neutral growth inhibitor, designated raphanusanin, was isolated in crystalline form from light-exposed Sakurajima radish (*Raphanus sativus* var. *hortensis* f. *gigantissimus* Makino) seedlings and identified as a new compound, 3-methoxy-4-methylthio-2-piperithione (Hasegawa et al. 1982). Applied raphanusanin inhibited the hypocotyl growth of etiolated radish and lettuce seedlings at concentrations higher than 1.5×10^{-6} M. A new growth inhibitor isolated from an acetone extract of light-exposed seedlings of Sakurajima radish was characterised as 2-thioxothiazolidine-4-carboxylic acid (Hase et al. 1983). Three growth inhibitors which might be involved in phototropism of Sakurajima radish (*Raphanus sativus* var. *hortensis* f. *gigantissimus* Makino) hypocotyls were isolated as crystalline forms from light-exposed radish seedlings and identified as *cis*- and *trans*-raphanusanins and 6-methoxy-2,3,4,5-tetrahydro-1,3-oxazepin-2-one (designated raphanusamide) (Hasegawa et al. 1986). The *cis*- and *trans*-raphanusanins inhibited the growth of etiolated radish hypocotyls at concentrations higher than 1.5 μmolar, raphanusamide at concentrations higher than 20 μmolar. Studies found that *cis*- and *trans*-raphanusanins caused growth inhibition by suppressing the action of auxin and/or cytokinin (Sakoda et al. 1991). A new growth inhibitor was isolated from light-grown radish seedlings and its structure determined as 3-(*E*)-(methylthio) methylene-2-pyrrolidinethione (Sakoda et al. 1990). Above concentrations of 30 mg/L, it inhibited hypocotyl growth in the etiolated cress seedling test.

During radish germination, there was a wide fluctuation of soluble sinapic acid esters. Two major constituents were rapidly degraded in the imbibition phase, and during cotyledon growth, new soluble sinapic acid esters appeared, from which three major components exhibited considerable quantitative changes in opposing directions (Strack 1977). Sinapine esterase that catalysed sinapine (a major phenolic compound in radish seeds) into sinapate and choline during seed germination was found in radish cotyledons (Nurmann and Strack 1979). Sinapine was isolated from radish seeds (Liu et al. 2002). The mean recovery rate for sinapine thiocyanate from radish seeds was 99.75 % and the amount ranged from 1.696 to 16.96 (Li and Jing 2010). The following components were identified in the metabolic pathway of sinapic acid and its ester derivatives in radish cotyledons: sinapoylglucose, sinapine (sinapoylcholine), sinapoylmalate and disinapoylglucose (Linscheid et al. 1980). Protein preparations from radish cotyledons converted the sinapoyl moiety of 1-sinapoylglucose to L-malate to form sinapoyl-L-malate via a sinapoyltransferase (Tkotz and Strack 1980). During the development of radish seedlings, transconjugation reactions of sinapine (*O*-sinapoylcholine) via transiently accumulating the intermediate 1-*O*-sinapoyl-β-D-glucose in the cotyledons led to

accumulation of *O*-sinapoyl-L-malate (Strack 1982). The first committed enzyme in sinapate ester biosynthesis was established as a glucosyltransferase (UDP-glucose–sinapate glucosyltransferase) that transferred the glucose moiety from UDP-glucose to the carboxyl group of sinapate (Strack 1982). The resulting β-acetal ester 1-*O*-sinapoyl-β-D-glucose (sinapoylglucose) served as acyl donor in subsequent transacylation reactions thus providing an alternative to CoA-dependent pathways (Mock and Strack 1993). A uridine 5′-diphosphoglucose–hydroxycinnamic acid acyl-glucosyltransferase (HCA-GT) catalysing the formation of 1-*O*-sinapoyl-β-glucose (EC 2.4.1.120) in seedlings of *Raphanus sativus* was partially purified (Mock and Strack 1993). The enzymes channelling sinapoylglucose into the major accumulating sinapate ester compounds had been defined as sinapoylglucose–malate sinapoyltransferase (SMT) and sinapoylglucose–choline sinapoyltransferase (SCT), respectively (Tkotz and Strack 1980; Strack et al. 1986). L-phenylalanine ammonia lyase (PAL) was not involved in sinapoyl derivative metabolism in radish (Strack et al. 1978). In-vivo inhibition of PAL activity with α-aminooxy-β-phenylpropionic acid (AOP) did not affect the accumulation of sinapoylglucose, whereas the formation of anthocyanins, flavonols and a feruloyl derivative was severely depressed. Administration of AOP to the intact seedling revealed I50 values to be 0.14 mM for pelargonidin, 0.16 mM for kaempferol and 0.18 mM for the feruloyl derivative. Biosynthesis of phosphatidylcholine in young radish seedlings was supplied with choline from degradation of the seed constituent sinapine (sinapoylcholine) (Strack 1981). During seedling development, the quantity of labelled sinapine rapidly decreased as a result of sinapine degradation with a concomitant label increase in free choline, phosphorylcholine and phosphatidylcholine. Approximately 50 % of the choline liberated from sinapine was consumed in the biosynthesis of phosphatidylcholine. Seedlings of red radish accumulated high amounts of free malic acid and sinapoylmalate, when grown on nitrate as the sole N-source (Dahlbender and Strack 1984). In the presence of ammonium (NO_3^-/NH_4^+-N, 1:2), both metabolites failed to accumulate, and the levels of arginine, asparagine, glutamine, histidine and serine were greatly increased. Sinapic acid esters, namely, 1-sinapoylglucose, sinapoylmalate, 6,3′-disinapoylsucrose and 1,2-disinapoylglucose from crude methanolic extracts from cotyledons of 6-day-old *R. sativus* seedlings, cultured on nutrient solution with NO_3^-/NH_4^+-N, were higher than when cultured on NO_3^--N. The extractable activity of 1-sinapoylglucose–L-malate sinapoyltransferase, an enzyme which plays a key role in channelling malic acid into the sinapic-acid metabolism of this plant, was positively correlated with the malic acid level in the cotyledons. From the results, it was proposed that free malic acid might be the likely candidate for regulating the activity of 1-sinapoylglucose–L-malate sinapoyltransferase. L-malate, sinapic acid esters and 1-sinapoylglucose–L-malate sinapoyltransferase (SMT) catalysing the synthesis of sinapoyl-L-malate were found in the vacuoles of protoplasts obtained from cotyledons of red radish (Sharma and Strack 1985). The epidermis and mesophyll tissues of radish cotyledons were found to contain sinapic acid esters (1-sinapoylglucose, sinapoyl-L-malate, 6,3′-disinapoylsucrose), kaempferol glycosides, free malic acid and enzyme involved in the synthesis of sinapoyl-L-malate, 1-sinapoylglucose–L-malate sinapoyltransferase (SMT) (Strack et al. 1985). The kaempferol glycosides were mainly localised in the upper epidermis of radish seedling cotyledons, while the sinapoyl esters were found in all tissues but differed markedly in their concentrations. Disinapoylsucrose was localised predominantly in the mesophyll, while most sinapoylmalate was found in the epidermal layers, as was most 1-sinapoylglucose–L-malate sinapoyltransferase (SMT) activity. Epidermal sinapoyl esters were restricted to guard cells and to guard mother cells and adjacent epidermal cells. Strack et al. (1986) afforded evidence indicating that the 1-sinapolyglucose–L-malate sinapoyltransferase (SMT) activity in radish cotyledons might be related to the metabolism of malic acid.

Sinapoyl glucose was found in radish sprouts (Herrmann 1989). Methyl sinapate, 1,2-disinapoyl-β-D-glucopyranoside and β-D-(3,4-

disinapoyl)fructofuranosyl-α-D-(6-sinapoyl)-glucopyranoside were isolated from radish sprouts (Takaya et al. 2003). The main phenolic acids represented in *R. sativus* grown in hydroponic culture in excess copper were chlorogenic, vanillic, caffeic, syringic, *p*-coumaric and ferulic acids, whereas the least represented were gallic, protocatechuic and *p*-hydroxybenzoic acids (Sgherri et al. 2003). The Cu contents increased with the treatment in both shoots and roots, maintaining in the roots a value eight- to tenfold higher than in the shoots. In both parts, phytochelatin-SH content reached the maximum at 5 μM copper and then decreased, reaching at 15 μM copper the control value in the roots and a value fivefold higher than the control value in the shoots. The phenolic acids as well as the total and reduced ascorbate contents increased with the intensification of copper treatment. Notwithstanding these changes, total ascorbate remained 35 % higher in the shoots than in the roots.

Phytochemicals in Flowers

Radish stigma diffusates were found to contain many protein bands; the molecular weights of some of the major fractions were estimated to be 15,000, 30,000–46,000 and 70,000 Da (Zhang et al. 1983). Glycine, glutamic acid, serine and aspartic acid were some of the predominant amino acids. The carbohydrate fraction of the glycoprotein consisted of arabinose 17.3 %, galactose 19.1 %, xylose 8.1 %, mannose 5.4 %, glucose 23.7 %, rhamnose and/or fucose 26.4 %. In the stigma surface diffusates, the content of protein was estimated to be 16 % and that carbohydrate was 11 %.

Antioxidant/Redox Activity

The antioxidative activity of hot water extract of daikon was higher than that of the ambient water extract (Katsuzaki et al. 2004). One of the antioxidants was isolated as L-tryptophan which changed to 5-hydroxytryptophan, another antioxidant in the rat liver microsome. Radish root extract reduced the levels of thiobarbituric acid reactive substance significantly in all treated albino rats as compared to the experimental control group (Chaturvedi 2008). It also increased the levels of reduced glutathione and increased the activity of catalase. The extract also inhibited in-vitro cumene hydroperoxide-induced lipid peroxidation. The results suggested that radish root extract afforded protection by strengthening the antioxidants like glutathione and catalase.

Among the different extraction solvents, methanolic extract of the leaves and stem showed potent reductive capacity, significantly inhibited linoleic acid peroxidation and displayed metal chelating activity (Beevi et al. 2010b). Additionally, they scavenged free radicals effectively with IC_{50} of 31 and 42 μg/mL for DPPH radical, 23 and 52 μg/mL for superoxide radical, 67 and 197 μg/mL for hydrogen peroxide and 56 and 62 μg/mL for nitric oxide, respectively. The leaves showed the most potent antioxidant and radical scavenging activity as compared to the stem, attributable to the higher polyphenolic content. The methanolic radish root extract showed significant ferric reducing ability, moderate metal chelating activity and strong radical scavenging activity (Beevi et al. 2012). Polyphenolic content in radish was estimated to be in the range 13.18–63.54 mg/g dry weight, with a considerable amount being obtained with polar solvents. Catechin was found to be the most abundant phenolic compound in water extract and sinapic acid, the predominant phenolic compound in methanolic, ethyl acetate and hexane extracts.

Red radish extract in which the major compounds were acylated pelargonidin derivatives appeared to form a complex with Fe^{3+} or Cu^{2+} (Wang et al. 2010). It displayed a concentration-dependant reducing power and scavenging effect against 2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) radicals (with $IC_{50} = 1.74$ mM). It could promote the cleavage of plasmid DNA with Cu(II)/H(2)O(2) or Cu(II) alone. The extract also showed growth inhibition of Bel-7402 cells at lower concentration. The results suggested that the formation of reactive oxygen species might be involved in the mechanism of DNA damage. The acylated pelargonidin deriva-

tives extracted from red radish could act as antioxidant and pro-oxidant, and their antioxidant and pro-oxidant properties were relative to the reaction conditions.

Hydrogen peroxide oxidation of glucoraphasatin (4-methylthio-3-butenyl GS) readily resulted in complete transformation into glucoraphenin (4-methylsulfinyl-3-butenyl GS). ABTS*+ radical caused complete decay of the glucosinolate in radish sprouts (Barillari et al. 2005). Even though not directly related to its radical scavenging activity, the assessed reducing capacity of glucoraphenin suggests that *R. sativus* sprouts might possess potential for health benefits. Spraying exogenous plant hormone methyl jasmonate (MeJA) upon radish sprout significantly increased the total phenolic content that resulted in the increasedDPPH*(2,2-diphenyl-1-picrylhydrazyl) free radical scavenging capacity (Kim et al. 2006). In addition, the phenylalanine ammonia lyase activity also increased by 60 % at 24 hours after MeJA treatment. However, the same treatment decreased the amount of 4-methylthio-3-butenyl isothiocyanate (MTBITC), a major isothiocyanate in radish sprout, and the activity of myrosinase, an enzyme related to produce isothiocyanates.

Glucoraphasatin (GRH) and its corresponding isothiocyanate (ITC), 4-methylthio-3-butenyl isothiocyanate (GRH-ITC), from radish sprouts, were able to quench the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical, with second-order rate constants of 14.0 and 43.1 M^{-1} s^{-1}, respectively (at 298 K in methanol), whereas the corresponding value measured for the reference antioxidant α-tocopherol was 425 M^{-1} s^{-1} (Papi et al. 2008). GRH reacted with H_2O_2 and *tert*-butyl hydroperoxide in water (pH 7.4) at 37 °C, with rate constants of 1.9×10^{-2} and 9.5×10^{-4} M^{-1} s^{-1} (paralleling recently developed synthetic antioxidants) being quantitatively (>97 %) converted to glucoraphenin.

Radish sprouts were between 9- and 59-fold more potent than the corresponding mature taproot at activating the antioxidant response element (ARE) in a stably transfected hepatoma cell line (Hanlon and Barnes 2011). The ARE activity of the radish sprouts and mature taproots was significantly correlated with the total isothiocyanate concentration of the radishes.

Among the 11 kinds of commonly available vegetables, the methanol extract of radish sprout (Japanese name 'kaiware daikon') exhibited the highest hydroxyl radical scavenging potency using the bleomycin–Fe method (1.8 times as L-ascorbic acid) (Takaya et al. 2003). Several sinapinic acid esters and flavonoids were isolated with high radical scavenging potency, which may contribute substantially to the activity. Black radish root juice exhibited significant antioxidant properties (Lugasi et al. 2005). Supplementation of the lipid-rich diet (20 % sunflower oil, 2 % cholesterol, 0.5 % cholic acid in normal chow) with black radish juice resulted in a significant improvement of antioxidant enzyme activities and the free radical scavenging capacity in hyperlipidaemic rats.

Anticancer Activity

The methanol extract of radish sprouts induced quinone reductase activity in a dose-dependent manner in the concentration range of 0.2–1.6 mg/mL with a maximum of a 3.5-fold increase in induction in murine Hepa1c1c7 cells (Lee and Lee 2006). The induction of quinone reductase by the extract was regulated at the transcriptional level. The dichloromethane (CH_2Cl_2) fraction of the extract showed the highest induction potency, while the other fractions were less potent. The results indicated that radish sprouts could be regarded as a safe and promising new dietary source for decreasing the risk of developing cancer as quinone reductase is known to play critical roles in protection against chemical carcinogens and other toxic xenobiotics.

Isothiocyanates from radish sprouts, 4-methylthio-3-butenyl isothiocyanate (GRH-ITC) and 4-methylsulfinyl-3-butenyl isothiocyanate (GRE-ITC), reduced cell proliferation in a dose-dependent manner and induced apoptosis in three human colon carcinoma cell lines (LoVo, HCT-116 and HT-29) (Papi et al. 2008).

The compounds significantly increased Bax and decreased Bcl-2 protein expression, as well as produce caspase-9 and PARP-1 cleavage after 3 days of exposure in the three cancer cell lines. GRH-ITC treatment was shown to have no toxicity with regard to normal human lymphocytes (−15 %) in comparison with sulforaphane from broccoli (complete growth inhibition). GRH and GRH-ITC were able to quench the 2,2-diphenyl-1-picrylhydrazyl radical. Barillari et al. (2008) found that administration of kaiware daikon extract (KDE), in combination with myrosinase at doses corresponding to 50 μM 4-methylthio-3-butenyl isothiocyanate (GRH-ITC) plus 15 μM 4-methylsulfinyl-3-butenyl isothiocyanate (GRE-ITC) (50 μM KDE-ITC) to three human cancer cell lines (LoVo, HCT-116 and HT-29), significantly reduced cell growth by 94–96 % of control in 6 days, outperforming pure GRH-ITC or GRE-ITC at the same dose. In contrast, the same treatment had no significant toxicity on normal human T lymphocytes. A 50 μM concentration of KDE-ITC had relevant apoptosis induction in all tested cancer cell lines. Unlike pure GRH or GRH-ITC, KDE also had significant chain-breaking antioxidant activity, retarding the 2,2′-azobis-(2-amidinopropanehydrochloride)(AAPH)-initiated autoxidation of methyl linoleate in sodium dodecyl sulfate (SDS) micelles at concentrations as low as 4.4 ppm (−50 % in oxygen consumption rate), and induced very fast quenching of DPPH radical. In another study, Kim et al. (2011) reported that the ethanol extract of radish leaves inhibited cell proliferation of MDA-MB-231 human breast cancer cells after 48 hours of incubation via the ErbB–Akt pathway. The extract significantly decreased protein expression and mRNA of ErbB-3 (epidermal growth factor receptor) and mRNA expression of Akt (protein kinase B); it increased significantly protein and mRNA expression of Bax and Bcl-2 (apoptosis regulators). Seven 4-methylthio-butanyl derivatives from radish seeds showed antiproliferative activity against the HCT-15 cancer cell, with IC_{50} values of 8.49–23.97 μM (Kim et al. 2014).

Nitrogen mustards *cis*-1-methoxy-2-deoxy-2-[*N*,*N-bis*(2 -chloroethyl)amino]spirobrassinol and *trans*-1-methoxy-2-deoxy-2-[*N*,*N-bis*(2 -chloroethyl)amino]spirobrassinol derived from 1-methoxyspirobrassinol, an indole phytoalexin produced by the Japanese radish, were designed as prospective dual-action compounds with DNA-alkylating effect and glutathione-depleting effects that may sensitise cancer cells to alkylating agents (Mezencev et al. 2009). Both new compounds demonstrated cytostatic/cytotoxic effects on various leukaemia and ovarian cancer cell lines and dsDNA-destabilising effects in-vitro. The *cis* isomer was the more promising of the two compounds, exerting earlier onset of anticancer effects on Jurkat cells via induction of apoptosis compared to the traditional alkylating anticancer agent melphalan. Additionally, it demonstrated higher potency on ovarian cancer OVCAR3 cell line and lower fold resistance between Jurkat and Jurkat-M cells selected for the resistance to melphalan. Mustard oil in 'Shibori Daikon' a variety of Japanese radish selectively inhibited the proliferation of H-ras-transformed derivative of rat fibroblast HR-3Y1-2, but not 3Y1 rat fibroblasts after 24 hours of treatment (Yamasaki et al. 2009). The selective inhibition was associated with transient oxidative stress via reduced glutathione (GSH) depletion and cell cycle G2/M arrest. The mustard oil extract was found to contain 95.6 % of 4-methylthio-3-butenyl isothiocyanate and 4.4 % of 4-methylthiobutyl isothiocyanate.

Hexane extract of radish root inhibited cell proliferation and induced apoptosis in human cancer cells by upregulation of pro-apoptotic genes and downregulation of antiapoptotic genes along with activation of Caspase-3 (Beevi et al. 2010a). The presence of several isothiocyanates (ITCs) such as 4-(methylthio)-3-butenyl isothiocyanate (MTBITC), 4-(methylthio)-3-butyl isothiocyanate (erucin), 4-methylpentyl isothiocyanate, 4-pentenyl isothiocyanate and sulforaphene was detected in the hexane extract. 4-(methylthio)-3-butenyl isothiocyanate (MTBITC) extracted from *Raphanus sativus* significantly inhibited nitroblue tetrazolium reduction by superoxide radicals in a nonenzymatic superoxide generating system, to scavenge free radicals and to cause a decrease in murine leukaemia cell line (L1210) cell growth (Salah-Abbès et al. 2010b). It also counteracted zearalenone oxidative stress

to BALB/c mice keratinocyte cell line (C5-O) through caspase-8 inhibition of apoptosis.

A low transformation of selenium into organic forms was observed in radish plants grown in Se(VI)-enriched culture media (Pedrero et al. 2006). On the contrary, in those plants exposed to selenite, >95 % of the total selenium was found as selenocysteine (SeCys2), selenomethionine (SeMet) and Se-methylselenocysteine (SeMetSeCys). The concentrations of these compounds in fresh samples remained almost unaltered after a simulated gastrointestinal digestion. Therefore, a high selenium content of Se-methylselenocysteine (65 %), previously reported as a cancer chemopreventive species, remained in the potentially bioabsorbable fraction. The results suggested that radish enriched in selenite could be a good choice as an organoselenium supplement for the human diet and animal feed.

Antimutagenic Activity

A correlation was found between the potency of antimutagenicity and the amount of 4-(methylthio)-3-butenyl isothiocyanate (MTBITC) in the n-hexane extracts of eight strains of daikon (Nakamura et al. 2001). Because the pure MTBITC also showed antimutagenicity, MTBITC was presumed to be the active antimutagen principle in n-hexane extracts of daikon. In addition, phenethyl isothiocyanate was found in a lesser amount (5–33 nmol/100 g) in eight strains of daikon, and allyl isothiocyanate and benzyl isothiocyanate were not detectable in any strains (<3 nmol/100 g). The amount of total isothiocyanate in grated daikon was 7.0 times higher than that in cut daikon measured after 30 minutes of cooking. Through eating habits, humans might be able to consume substantial amounts of the antimutagen MTBITC from dishes using the grated form of wild strains of daikon. 4-(methylthio)-3-butenyl isothiocyanate (MTBITC) extracted from Tunisian radish was found to prevent genotoxicity and clastogenicity of zearalenone in BALB/c mice and in in-vitro (Salah-Abbès et al. 2009c).

Antidiabetic Activity

Normal rats fed with a diet containing Japanese radish sprout (JRS) had lower plasma levels of total cholesterol (TC), triglycerides (TG), phospholipids (PL), fructosamine, glucose and insulin and higher plasma levels of low-density lipoprotein cholesterol, whereas the JRS-fed streptozotocin-induced diabetic rats showed lower plasma levels of fructosamine, glucose and insulin without changes in the plasma lipid parameters (Taniguchi et al. 2006). JRS also decreased the hepatic TC, TG and PL levels in the normal rats and the TG level in the diabetic rats. The results showed that JRS had a hypoglycaemic activity in both the normal and diabetic rats and partly improved lipid metabolism in the normal rats. JRS also had the potential to alleviate hyperglycaemia in cases of diabetes and may serve in the primary prevention of diabetes mellitus. In subsequent study, they found that the water-soluble (WSE) and fat-soluble extracts (FSE) from Japanese radish sprouts exerted dierring effects on carbohydrate and lipid metabolism in normal and streptozotocin-induced diabetic rats (Taniguchi et al. 2007). FSE suppressed insulin secretion and improved lipid metabolism in the normal rats. The effect of WSE was different from that of the FSE as it decreased blood glucose levels without increasing insulin secretion and also lowered glycoalbumin and fructosamine levels in the streptozotocin (STZ)-induced diabetic rats.

Radish root juice extract at a dose of 300 mg/kg BW was identified as the most effective dose lowering blood glucose level (BGL) by 33.4 % at 6 hours during fasting blood glucose studies in normal rats (Shukla et al. 2011a). However, the glucose tolerance test (GTT) revealed the maximum reduction of 15.9 % in BGL at 3 hours in normal rats with the same dose, whereas the reduction observed was by 23.8 and 28.3 % in streptozotocin (STZ)-induced sub- and mild-diabetic rats, respectively, at the same interval of time. The data suggested that radish root juice had hypoglycaemic potential coupled with antidiabetic efficacy.

Anti-inflammatory Activity

The 4-methylthio-butanyl derivative, sinapoyl desulfoglucoraphenin, isolated from radish seeds, exhibited anti-neuroinflammatory effect in lipopolysaccharide-stimulated murine microglia BV-2 cells (Kim et al. 2014). It significantly inhibited nitrite oxide production with IC_{50} values of 45.36 μM. Moreover, it also reduced the protein expression of inducible nitric oxide synthase.

After treatment with granules from black radish root, all of the histopathological changes and parameters of the redox state (epithelial lining disruption, reduction in the number of enterocytes and goblet cells and the presence of inflammatory cells) caused by the fat-rich diet were improved (Sipos et al. 2002). The structure of the epithelial cells was similar to the controls, the number of goblet cells increased and no inflammation was observed.

Both radish leaf juice and root juice significantly reduced carrageenan- and formalin-induced paw oedema in rats, but radish leaf juice compared to root juice produced more significant anti-inflammatory effect in both acute and chronic models of inflammation (Kamble et al. 2013). However, the anti-inflammatory effect of radish leaf juice was less than the standard drug diclofenac sodium.

Spasmogenic Activity

Aqueous extract of radish seeds containing terpenes, flavonoids, phenols, alkaloids and saponins showed a spasmogenic effect in isolated rabbit jejunum and ileum, rat stomach fundus and ileum and guinea pig ileum and jejunum (Ghayur et al. 2005). The extract was around ten times more potent in the guinea pig tissues, and this effect was resistant to atropine, pyrilamine or SB203186, while the spasmogenic effect in the rat and rabbit tissues was atropine sensitive. The extract exhibited atropine-sensitive GI (gastrointestinal) prokinetic and laxative effects in-vivo in mice. In the atropinised rabbit jejunum, radish seed extract produced a spasmolytic effect independent of Ca^{2+} or K^+ channels and adrenergic or opioid receptor involvement. Activity-directed fractionation of the extract yielded four fractions, all showing effects similar to that of the parent extract. The extract and its fractions were found to be nonlethal up to 10 g/kg in mice for 24 hours, except for the petroleum fraction, which showed 50 % mortality at high doses. Some known radish compounds (spermine, spermidine, putrescine and sinigrin) were also tested and found to be devoid of any activity. A mild relaxant effect was also observed in rabbit jejunum at the lower doses (0.1–0.3 mg/mL) but not against K^+-induced contractions, ruling out a calcium channel-blocking effect. In guinea pig ileum, radish leaf extract exhibited a stimulant effect resistant to atropine while sensitive to pyrilamine pretreatment. The findings suggested the presence of species-dependent gastrointestinal effects of radish mediated partially through cholinergic receptors in rabbit and rat tissues but through histaminergic activation in the guinea pig. The crude radish leaf extract exhibited a dose-dependent (0.03–5.0 mg/mL) spasmogenicity in guinea pig ileum and colon (Gilani and Ghayur 2004). The effect was insensitive to atropine pretreatment but was completely abolished by pyrilamine indicating involvement of histaminergic (H(1)) receptors. The contractile effect at high doses (3.0–5.0 mg/mL) was followed by relaxation. The extract also enhanced the transit of charcoal meal in mice at 30–100 mg/kg. The petroleum spirit, chloroform and aqueous fractions all showed histaminergic activity in the ileum, aqueous fraction being more potent. The results indicated the presence of a histaminergic component(s) along with a weak spasmolytic factor thus providing sound mechanistic basis for the traditional use of the plant in constipation. In subsequent studies, they found that administration of radish and betel nut extracts to isolated rabbit gall bladder tissues modulated gall bladder contractility in a concentration-dependent manner similar to carbachol, a muscarinic receptor agonist (Ghayur and Gilani 2012). The stimulant effect of the extract, as well as that of carbachol, was completely blocked in the presence of atropine, a muscarinic antagonist, indicating similarity in the mechanism of action of the extracts with carbachol. The result showed the potential

of these extracts to contract the gall bladder and to subsequently increase bile secretion.

Hepatoprotective Activity

Acute and chronic administration of radish leaf powder, its water and ethanol extracts significantly decreased the elevated activity of serum glutamate oxaloacetate transaminase (SGOT), serum glutamate aspartate transaminase (SGPT), serum lactate dehydrogenase (SLDH), serum alkaline phosphatase (SAP) and serum total bilirubin in paracetamol-induced hepatotoxicity in rabbits (Anwar and Ahmad 2006). Crude radish leaf powder, its water and ethanol extracts produced nonsignificant effect on total protein contents. In a separate study, administration of radish root methanol extract to albino rats exerted a protective effect on paracetamol-induced hepatotoxicity in a dose-dependent manner (Chaturvedi et al. 2007; Chaturdevi and Machacha 2007). Radish extract reduced the levels of thiobarbituric acid reactive substances (TBARS), SGOT and SGPT and increased the level of GSH and reduced glutathione (GSH) and catalase. The extract reduced lipid peroxidation induced by paracetamol and reverted the levels of SGOT and SGPT to normal, indicating liver recovery. It also restored GSH levels and recovery of catalase activity. Oral administration of radish extract of 200 and 400 mg/kg body weight protected Wistar albino rats against carbon tetrachloride-induced hepatotoxicity (Mohammed et al. 2008). The extract inhibited the increase in serum aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase (ALP) and bilirubin concentrations besides adverse histopathological changes induced by CCL_4. Studies found that oral administration of the sulfur-radish extract and of sulforaphane after CCL_4-induced liver injury in mice both decreased the serum level of alanine aminotransferase, reduced the necrotic zones, inhibited lipid peroxidation and induced phase 2 enzymes without affecting cytochrome P450 2E1 (CYP2E1) (Baek et al. 2008). The results suggested that the administration of the sulfur-radish extract and of sulforaphane may partially prevent CCL_4-induced hepatotoxicity, possibly by indirectly acting as an antioxidant by improving the detoxification system.

Administration of radish extract enhanced the antioxidant status and protected against oxidative stress in the liver and kidney induced by zearalenone (a nonsteroidal oestrogenic mycotoxin) in BALB/c mice (Salah-Abbès et al. 2008b). Co-treatment of male BALB/c mice with *R. sativus* extract plus zearalenone prevented the hepatotoxic damage effects of zearalenone (Salah-Abbès et al. 2009b). Radish extract succeeded in reversing hepatotoxic condition back to normal levels for all studied parameters.

Radish enzyme extract showed hepatoprotective activity on tacrine-induced cytotoxicity in HepG2 cells with EC_{50} value of 1,250 μg/mL (Lee et al. 2012). Oral administration of the extract at doses of 50 and 100 mg/kg and silymarin at a dose of 50 mg/kg significantly reduced the elevated levels of serum enzyme markers induced by CCL_4.

Enzyme Detoxification Activity

The crude aqueous extract from 0.3 to 3 mg of dry Spanish black radish material (SBR) increased the activity of the phase II detoxification enzyme quinone reductase in the human hepatoma HepG2 cell line with a maximal effect at a concentration of 1 mg/mL (Hanlon et al. 2007). Treatment of HepG2 cells with the crude aqueous extract of 1 mg of SBR per mL also significantly induced the expression of mRNA corresponding to the phase I detoxification enzymes, cytochrome P450 (CYP)1A1, CYP1A2 and CYP1B1, as well as the phase II detoxification enzymes, quinone reductase, haem oxygenase 1 and thioredoxin reductase 1. They showed that while glucoraphasatin addition was ineffective, the isothiocyanate metabolite of glucoraphasatin, 4-methylthio-3-butenyl isothiocyanate (MIBITC), significantly induced phase II detoxification enzymes at a concentration of 10 μM. Further, Hanlon et al. (2009) demonstrated that the crude aqueous extract of Spanish black radish and the isothiocyanate metabolite of glucoraphasatin, 4-methylthio-3-butenyl isothiocyanate (MIBITC), were potent inducers of phase

I detoxification enzymes, cytochrome P450 (CYP)1A1, CYP1A2 and CYP1B1, as well as the phase II detoxification enzymes, quinone reductase, haem oxygenase 1 and thioredoxin reductase 1 in the HepG2 cell line.

In HepG2 cells, raphasatin induced quinone reductase activity and the RNA expression of several phase 1 and 2 detoxification enzymes by a significantly greater amount than the degradation products of raphasatin (Scholl et al. 2011). Raphasatin, but not its degradation products, activated the antioxidant response element (ARE) in a stably transfected reporter cell line. Mice fed a diet consisting of 20 % freeze-dried radishes for 2 weeks had significantly higher liver expression of cytochrome P450 (CYP)1A1, 1A2, quinone reductase, microsomal epoxide hydrolase and glutathione S-transferase α2 than mice fed with a nutritionally matched control diet.

In an animal study, N'jai et al. (2012) found expression of phase I and II detoxification enzymes was significantly greater for mice fed with Spanish black radishes than control diet. Six hours after 7,12-dimethylbenz(a)anthracene (DMBA) administration, the blood levels of DMBA in mice fed with the radish diet were significantly lower than mice fed with a control diet. DMBA reduced bone marrow cells in mice fed with a control diet to a significantly greater extent than mice fed with the black radish diet. Colony-forming assays demonstrated that mice on black radish diet had (1) less reduction in lymphoid CFU-preB progenitor cells, (2) greater recovery of CFU-preB progenitor cells at 168 hours and (3) less reduction of CFU-GM progenitor cells at 6 hours. Thus, mice fed with a 20 % black radish diet for 2 weeks had greater expression of detoxification enzymes, faster metabolism of DMBA and a reduction in DMBA-induced bone marrow toxicity.

Antihypertensive Activity

Radish seed extract tested positive for the presence of saponins, flavonoids, tannins, phenols and alkaloids and caused a dose-dependent (0.1–3 mg/kg) fall in blood pressure and heart rate of rats that was mediated via an atropine-sensitive pathway (Ghayur and Gilani 2006). In isolated guinea pig atria, the extract showed dose-dependent (0.03–3.0 mg/mL) inhibition of force and rate of contractions. In the atropine-treated tissues, the inhibitory effect was abolished and a cardiac stimulant effect was unmasked which was resistant to adrenergic and serotonergic receptor blockade. In the endothelium-intact rat aorta, the extract inhibited phenylephrine-induced contractions, which was blocked by atropine and Nomega-Nitro-L-arginine methyl ester hydrochloride which was also absent in the endothelium-denuded preparations. The data showed that the cardiovascular inhibitory effects of the plant were mediated through activation of muscarinic receptors thus possibly justifying its use in hypertension. Administration of soluble alkaloids of Raphani Semen significantly lowered the blood pressure of spontaneously hypertensive rats (SHR) and improved the process of cardiovascular remodelling (Li et al. 2007). Laiju extract (LJE) from Raphani Semen and Flos Chrysanthemi exhibited antihypertensive effect in renal hypertensive rat (RHR) and spontaneous hypertensive rat (SHR) (Chen et al. 2007). Compared with saline control, blood pressure was significantly lowered at 6 and 5 hours in high and moderate LJE, respectively, in both RHR and SHR groups. However, blood pressure was significantly lowered at 2 and 3 hours in low LJE in both RHR and SHR groups, respectively. Compared with saline control, blood pressure remained significantly lower in SHR in all dosage groups with a single daily dose for 28 days of study. The results suggested that LJE had potential in the preventive management of hypertension.

The flavonoid kaempferol 3,7-di-*O*-α-L-rhamnopyranoside (lespedin) isolated from radish leaves was found to have hypotensor activity (Muminova et al. 2006).

Antiatherosclerotic Activity

The abnormal growth of vascular smooth muscle cells (VSMC) is a prominent feature of vascular disease, including atherosclerosis and

restenosis after angioplasty. Treatment with Korean white radish extract decreased the viability of VSMC by 35 % after 24 hours treatment (Suh et al. 2006). Radish extract showed potent inhibitory effects on the DNA synthesis of cultured VSMC. In addition, radish extract induced apoptosis using cell death ELISA assay. These inhibitory effects were associated with G1 cell cycle arrest. Four active isothiocyanate (ITC) were isolated from the hexane radish extract 4-(methylthio)-3-butenyl isothiocyanate (MTBITC), allyl isothiocyanate (AITC), benzyl isothiocyanate (BITC) and phenethyl isothiocyanate (PEITC). When the VSMC were treated with ITC, the cell viability was significantly decreased.

Antimicrobial Activity

An antibacterial principle designated raphanin was isolated from radish seeds (Ivanovics and Horvath 1947). It was inhibitory to the growth of *Staphylococcus* and coliform bacteria. The crude juices of *Raphanus sativus* was found to be strongly inhibitory in-vitro against *Escherichia coli*, *Pseudomonas pyocyaneus*, *Salmonella typhi* and *Bacillus subtilis* (Abdou et al. 1972). An antifungal nonspecific lipid transfer protein composed of two 9 KD subunits and possessing 43 amino acids was isolated from radish seed (Terras et al. 1992b). In low ionic strength medium, it exhibited in-vitro antifungal activity with IC_{50} values of 48 µg/mL for *Alternaria brassicicola*, 41 µg/mL for *Alternaria pisi*, 45 µg/mL for *Botrytis cinerea*, 25 µg/mL for *Colletotrichum lindemuthianum*, 20 µg/mL for *Fusarium culmorum*, 54 µg/mL for *Fusarium oxysporum* f.sp. *lycopersici*, 58 µg/mL for *Fusarium oxysporum* f.sp. *pisi*, 100 µg/mL for *Nectria haematococca*, 18 µg/mL for *Phoma betae*, 10 µg/mL for *Pyricularia oryzae*, 30 µg/mL for *Trichoderma hamatum* and 7 µg/mL for *Verticillium dahliae*. Two homologous, 5 kD, cysteine-rich proteins designated *Raphanus sativus* antifungal protein 1 (Rs-AFP1) and 2 (Rs-AFP2) from radish seeds were found to exhibit potent antifungal activity in-vitro (Terras et al. 1992b, 1995). Their antibiotic activity showed a high degree of specificity to filamentous fungi. The radish 2S storage albumins in the seeds were identified as the second novel class of antifungal proteins. All isoforms inhibit the growth of different plant pathogenic fungi and some bacteria. However, their antimicrobial activities were strongly antagonised by cations. Two induced radish leaf proteins (designated Rs-AFP3 and Rs-AFP4) were purified and shown to be homologous to seed Rs-AFPs and to exert similar antifungal activity in-vitro (Terras et al. 1995). Rs-AFP2, a 51 amino acid cysteine-rich peptide isolated from radish seeds, exhibited potent inhibitory activity against filamentous fungi (Alves et al. 1994). A cDNA clone encoding the Rs-AFP2 preprotein was modified by recombinant DNA methods to allow expression in the yeast *Saccharomyces cerevisiae*.

4-methylthio-3-butenyl isothiocyanate (MTBI), the pungent principle in radish, exhibited antimicrobial activity in-vitro (Uda et al. 1993b). Among the tested Gram-negative bacterial strains (*Escherichia coli*, *Enterobacter cloacae*, *Salmonella typhimurium*, *Proteus vulgaris*), the growth of *E. cloacae* was most strongly affected; the growth inhibition of the other Gram-negative bacterial strains was relatively lower. In contrast, the Gram-positive strains (*Staphylococcus aureus* S-6, *Staphylococcus epidermidis*, *Bacillus subtilis*, *Bacillus cereus* var. *mycoides*) were more sensitive to 2.5–7.5 µmol MTBI. Growth of *B. cereus* was highly inhibited, and *S. aureus* was also relatively sensitive. At 2.5–7.5 µmol, MTBI inhibited the growth of the yeasts (*Candida valida*, *Debaryomyces hansenii*, *Hansenula anomala*) and fungi (*Alternaria helianthi*, *Cladosporium colocasiae*, *Eurotium chevalieri*, *Penicillium frequentans*, *Mucor racemosus* f. *racemosus*) far more strongly than that of the bacteria. Especially, the growth of *A. helianthi* and *C. colocasiae* was almost completely inhibited by 5.0–7.5 µmol of MTBI. A strong inhibitory effect was also observed in E. *chevalier* and the yeast *C. valida*. Two antimicrobial components were found in the water-soluble products obtained by degradation of 4-methylthio-3-butenyl isothiocyanate, the

pungent principle of radish, of which the major one was isolated and indentified to be 2-thioxo-3-pyrrolidinecarbaldehyde (TPC) (Uda et al. 1993a). The identified compound exhibited prominent growth inhibition on the fungi (*Alternaria helianthi*, *Cladosporium colocasiae*, *Eurotium chevalieri*, *Mucor racemosus* f. *racemosus*, *Penicillium frequentans*, *Penicillium expansum*, *Penicillium martensii*, *Aspergillus candidus*, *Aspergillus fumigatus*) and Gram-positive bacteria (*Staphylococcus aureus* S-6, *Staphylococcus epidermidis*, *Bacillus subtilis*, *Bacillus cereus* var. *mycoides*, *Streptococcus faecalis*). The inhibitory effect on the yeasts (*Candida valida*, *Candida lactis-condensi*, *Debaryomyces hansenii*, *Hansenula anomala*, *Zygosaccharomyces rouxii*) and Gram-negative bacteria (*Enterobacter cloacae*, *Salmonella typhimurium*, *Proteus vulgaris*, *Pseudomonas aeruginosa*) except for *Escherichia coli* was the least among the tested microorganisms. The minimum inhibitory concentration (MIC) of 2-thioxo-3-pyrrolidinecarbaldehyde (TPC) was determined by strains of microbes (Matsuoka et al. 1997). MICs of 100 μg/mL were obtained for the fungi *Alternaria helianthi*, *Aspergillus candidus* and *Aspergillus fumigatus*; MICs of 200 μg/mL for *Cladosporium colocasiae*, *Eurotium chevalieri*, *Neurospora crassa*; and MICs of 400 ug/mL for *Mucor racemosus f. racemosus*, *Penicillium frequentans*, *Penicillium expansum* and *Penicillium martensii*. Yeasts were less sensitive with MICs of 400 μg/mL for *Candida albicans* and *Saccharomyces bayanus* and 800 μg/mL for *Candida valida*, *Debaryomyces hansenii and Hansenula anomala*. MICs obtained for Gram-negative bacteria were 200 μg/mL for *Enterobacter cloacae*, *Pseudomonas aeruginosa* and *Salmonella typhimurium* and 100 μg/mL for *Escherichia coli* and *Proteus vulgaris*. For the Gram-positive bacteria, the most sensitive was *Bacillus subtilis* with MIC of 50 μg/mL, followed by *Staphylococcus aureus* and *Staphylococcus epidermidis* at 100 μg/mL and Bacillus cereus and *Enterococcus faecalis* at 200 μg/mL. The antifungal and antibacterial actions of TPC were due to the sporicidal and bactericidal activities. In *S. epidermidis*, a dose-dependent inhibition of the uptakes of both oxygen and radioactive precursors was observed, suggesting that TPC caused damage to the mitochondrial functions and biosynthetic systems. The ethanol and methanol extracts of radish seeds exhibited in-vitro antibacterial activity against *Escherichia coli*, *Klebsiella pneumonia*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Shigella sonnei*, *Salmonella typhi* and *Salmonella paratyphi* (Ahmad et al. 2013).

Rs-AFP2 (*Raphanus sativus* antifungal peptide 2), an antifungal plant defensin isolated from radish seed, was found to interact with glucosylceramides (GlcCer) in membranes of susceptible yeast and fungi and induced membrane permeabilisation and fungal cell death (Aerts et al. 2007). It was shown that Rs-AFP2 induced reactive oxygen species (ROS) in *Candida albicans* wild type in a dose-dependent manner, but not at all in an Rs-AFP2-resistant Deltagcs *C. albicans* mutant that lacked the Rs-AFP2-binding site in its membranes. The findings indicated that upstream binding of Rs-AFP2 to GlcCer was essential for ROS production leading to yeast cell death. They also demonstrated that deletion of *C. albicans* metacaspase 1, encoding the only reported (putative) caspase in *C. albicans*, significantly affected caspase activation by the apoptotic stimulus acetic acid, but not by Rs-AFP2 (Aerts et al. 2009). Their data indicated the existence of at least two different types of caspases or caspase-like proteases in *C. albicans*.

The acetone and hexane fractions of radish root, stem and leaf exhibited selective antibacterial activity against *Bacillus subtilis*, *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Enterococcus faecalis*, *Salmonella typhimurium*, *Enterobacter aerogenes*, *Enterobacter cloacae* and *Escherichia coli* (Beevi et al. 2009). Antibacterial activity was strongest in the acetone fraction of root with larger zone of inhibition and lower minimum inhibitory concentration. The results obtained were comparable to that with standard antibiotics. Of the different parts of *R. sativus* studied, root tended to be more active than the stem and

leaf extracts in inhibiting the bacterial growth. Five different ITCs such as allyl isothiocyanate (AITC), phenyl isothiocyanate (PITC), benzyl isothiocyanate (BITC), phenethyl isothiocyanate and 4-(methylthio)-3-butenyl isothiocyanate (MTBITC) were identified in different parts of the plant. The low linear correlation between the total ITC content and antibacterial activity implied that bacterial growth inhibitory ability of *R. sativus* was not dependent on the total ITC content. However, the antibacterial activity of *R. sativus* was well correlated with AITC, PITC and BITC for all organisms except for *Enterococcus faecalis*, whose inhibitory effect was more related to MTBITC.

Radish root juice exhibited considerable antimicrobial activity in-vitro against five bacterial strains, viz., *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Enterococcus faecalis* and *Escherichia coli* with minimum inhibitory concentration (MIC) ranging from 0.078 to 0.625 mg/mL (Shukla et al. 2011b). Ethanolic and ethyl acetate extracts of radish root peels were the most effective of all extracts against bacterial strains tested (Janjua et al. 2013). Ethyl acetate extract of radish root peels was most effective against *Staphylococcus aureus*, *Bacillus subtilis*, *Salmonella typhi* and *Klebsiella pneumonia*. The ethanol extract had the highest zone of inhibition against *Micrococcus luteus*, *Pseudomonas aeruginosa*, *Bordetella bronchiseptica* and *Enterobacter aerogenes.*

Antiviral Activity

Administration of black radish aqueous extract by intranasal instillations to mice before inoculation of the influenza virus A/PR 8/34 (H1N1) strain protected against the experimental influenza infection (Prahoveanu and Eşanu 1987, 1990). A significant decrease of the haemagglutinin titre of the mouse lung homogenate was noted, as well as a decrease of the mortality rate and a significant increase of the rate of survival as compared to the untreated control.

Antilithiatic and Diuretic Activities

Administration of the aqueous extract of radish bark to rats with artificially induced urolithiasis significantly decreased the weight of stones compared to untreated urolithiatic rats (Vargas et al. 1999). This extract showed an increase in the 24 hour urine volume as compared to the control. After treatment with black radish root juice for 6 days of female C57BL/6 mice with induced gall bladder lithiasis, cholesterol gallstones were eradicated significantly in the gall bladder of mice; cholesterol and triglycerides levels were decreased, and there was also an increase in levels of HDL (Castro-Torres et al. 2012, 2014).

Immunoprotective Activity

Administration of radish extract was effective in protecting against zearalenone-induced immunological disorders in BALB/c mice (Salah-Abbès et al. 2008a). Mice treated with radish extract (5, 10 or 15 mg/kg) for 7 days before, during or after zearalenone treatment showed a significant improvement in lymphocyte, immunoglobulin profile, T-cell subtypes, B cells and proinflammatory cytokines. Moreover, treatment with the highest dose of radish extract (15 mg/k) enhanced the release of tumour necrosis factor-alpha and interleukin 1beta, but the other parameters were comparable with those of the control. Radish extract was found to be effective for the protection of high-dose zearalenone immunotoxication in BALB/c mice (Salah-Abbès et al. 2010a). The extract at 15 and 30 mg/kg BW reduced the deleterious effects in immunological parameters of high subchronic doses of 40 and 80 mg of zearalenone/kg BW on modulation of lipopolysaccharide (LPS). Radish extract was found to be effective for the protection of high-dose zearalenone immunotoxication in BALB/c mice (Salah-Abbès et al. 2010a). The extract at 15 and 30 mg/kg BW reduced the deleterious effects in immunological parameters of high subchronic doses of 40 and 80 mg of zearalenone/kg BW on modulation of lipopolysaccharide (LPS).

Salah-Abbès et al. (2014) found that radish extract prevented cadmium-induced immunotoxic and biochemical alterations in rats. Treatment with $CdCl_2$ alone resulted in significant decreases in plasma levels of total protein, triglycerides, creatine kinase, creatinine, IgG and IgA, T-lymphocyte subtypes ($CD4^+$, $CD3^+$, $CD56^+$ and $CD8^+$) and thymic and hepatic indices (relative weights). Conversely, $CdCl_2$ treatment caused significant increases in serum LDH, AST and ALT, in the formation/release of proinflammatory cytokines (IL-1 and TNF-α) and in the relative weights of host spleen and kidneys. Rats treated with radish extract alone had no discernable changes compared to the controls with regard to all test parameters. Combined treatment of $CdCl_2$ and radish extract at any dose resulted in a significant improvement of all test parameters compared to those seen with cadmium alone.

Choleretic Activity

Studies showed that administration of 1.5 g/kg of body weight radish sprouts (Kaiware Daikon) extract (containing 10.5 % w/w glucosinolate glucoraphasatin) for four consecutive days had antioxidant properties and significantly induced bile flow in rats (Barillari et al. 2006).

Gastroprotective Activity

Oral administration of freshly squeezed radish juice (FRJ) in doses of 2 and 4 mL/200 g BW significantly inhibited gastric ulcer formation induced by necrotising agents (ethanol, sodium hydroxide and sodium chloride), hypothermic restraint stress and indomethacin (Algasoumi et al. 2008). The FRJ also replenished the ethanol-induced depleted gastric wall mucus secretion and nonprotein sulfhydryl (NPSH) concentrations in rats. Phytochemical screening showed the presence of flavonoids, anthocyanins and sulfurated constituents.

Studies by Ahn et al. (2013) found that pretreatment with purple Bordeaux radish (PBR) extract at doses of 500 and 1,000 mg/kg, but not 250 mg/kg, significantly ameliorated ethanol-induced gastric haemorrhages in rats. The immunoreactivities of inducible nitric oxide (iNOS) and its by-product nitrotyrosine in the gastric mucosa of ethanol-treated rats pretreated with 500 mg/kg PBR extract were significantly reduced, as compared with rats treated with ethanol alone, the findings suggested that the gastroprotective effect of PBR could be mediated partly by the antioxidative activity of the extract.

Antidiarrhoeal Activity

Sinapine at 300 and 600 mg/Kg reduced the frequency or incidence of purging induced by castor oil or senna in mice, in a dose-dependent manner (Zhang and Shen 1996). Sinapine inhibited the gastrointestinal propellant rate of charcoal ink in normal mice, but the inhibition was weak and was not enhanced in a dose-dependent manner.

Skin Anti-ageing/Whitening Activity

The freeze-dried radish root juice showed higher potency of tyrosinase inhibition (IC_{50} = 3.09 mg/mL) than the methanolic extract (IC_{50} = 9.62 mg/mL) (Jakmatakul et al. 2009). Also, the scavenging effects of the freeze-dried juice on DPPH radical, superoxide anion radical and singlet oxygen were greater than the methanolic extract, with the respective IC_{50} values of 0.64, 4.20 and 1.42 mg/mL for the freeze-dried juice and 1.25, 6.28 and 2.40 mg/mL for the methanolic extract. The contents of total phenolics, total flavonoids and L-ascorbic acid (as per 1 mg of the dried extract) were found to be 10.09, 0.51 and 24.11 μg for the freeze-dried juice and 6.59, 0.33 and 8.28 μg for the methanolic extract, respectively. The higher contents of phenolic compounds and L-ascorbic acid in the freeze-dried juice appeared to be responsible for its greater

antityrosinase and antioxidant activities. The extract of *R. sativus* root appeared to be a good candidate for application as a natural skin whitening/skin anti-ageing agent due to its abilities to inhibit tyrosinase and scavenge several types of reactive oxygen species.

Rasatiol, isolated from radish seed, accelerated dermal fibroblast growth in a dose-dependent manner and increased the production of type 1 collagen, fibronectin and elastin (Roh et al. 2013). Phosphorylation of p42/44 extracellular signal-regulated kinase, p38 mitogen-activated protein kinase and Akt was remarkably increased by rasatiol, indicating that enhanced extracellular matrix production was linked to the activation of intracellular signalling cascades. The results indicated that rasatiol stimulated the fibrous components of production and may be applied to the maintenance of skin texture.

Reproductive Toxicity Protective Activity

Radish extract, rich in many antioxidant compounds, was safe and succeeded in counteracting the oxidative stress and protected against zearalenone-induced toxicological effects (decreased sperm number, testosterone level and antioxidant enzyme status) in male BALB/c mice (Salah-Abbès et al. 2009a). The extract also exhibited antigenotoxic effect in germ cells.

Laxative Activity

Administration of radish leaf aqueous extract and radish leaf juice to Wistar rats exerted significantly increased faecal output in loperamide-induced constipation and laxative activity test (Dande et al. 2014). Both the extract and the juice increased the distance covered in charcoal meal test and increased the water–ion secretion in electrolyte secretion test indicating laxative activity of *Raphanus sativus* leaf.

Antithyroid Activity

Makhkamov and Latipov (1965) reported a decrease in thyroid hormone in rats fed with radish. Upon hydrolysis, 3-indolylmethyl glucosinolate was reported to produce the thiocyanate (SCN) ion which, when administered over a prolonged period, will reduce the iodine available to the thyroid for incorporation into the thyroid hormone (Greer 1950).

Boiled extracts of radish showed maximum inhibition of thyroid peroxidase activity in-vitro followed by cooked and raw extracts (Chandra et al. 2004). After chronic radish feeding, increased weight of thyroid gland, decreased thyroid peroxidase activity, reduced thyroid hormone profiles and elevated level of thyrotropin were observed in albino rats resembling a relative state of hypoactive thyroid gland in comparison to control even after supplementation of adequate iodine (Chandra et al. 2006).

Food Safety Studies

Biogenic amines putrescine, cadaverine, histamine, tyramine, spermidine and spermine increased during broccoli and radish sprout production although these levels were below those permitted by legislation (5 mg/100 g of edible food) (Martínez-Villaluenga et al. 2008). Broccoli and radish sprouts contained numbers of mesophilic, psychrotrophic, total and faecal coliform bacteria which were the usual counts for minimally processed germinated seeds. They found that broccoli and radish sprouts demonstrated no toxic effects on proliferation and viability of HL-60 cells and should be included in our diets as healthy and safe fresh foods. Raphani Semen processed by roasting was reported to exhibit some adverse effects on mice (Sham et al. 2013). Additionally, erucic acid, the main fatty acid in Raphani Semen, was shown to enhance the toxicity of doxorubicin. Thus, Raphani Semen has a potential risk of causing toxicity and drug interaction.

Allergy Issues

A case of allergic contact dermatitis from the radish was reported in a waitress aged 38 years (Mitchell and Jordan 1974). The mixture of sinigrin, the thioglucoside of allyl *iso*thiocyanate, mixed in petrolatum with the enzyme myrosinase produced a positive patch test reaction. A more recent case of generalised urticaria after ingestion of radish was reported by Damiani et al. 2011).

Traditional Medicinal Uses

Almost all parts of radish plant including leaves, seeds and roots are utilised in medicine (Mayer 1981; Stuart 2013). The fresh juice obtained from leaves is diuretic, laxative, and used for diarrhoea, dropsy and general anasarca. Roots are considered stimulant, carminative and corrective, antiscorbutic and used for urinary complaints, haemorrhoids, gastrodynia pains and various gastric ailments. Roots are crushed and applied locally as dressing or poultice for burns, scalds, ecchymoses or foetid or smelly feet. Root decoction is employed for fever and to bring out the rash in eruptive fevers. Seeds are considered expectorant, digestive, diuretic, laxative, stimulant, carminative and lithotriptic and used to promote the flow of urine, bowel movements and menstruation. Flowers are considered cholagogue.

Lai fu zi (radish) is employed in traditional Chinese medicine (TCM) for treatment of gastrointestinal disorder and as expectorant in China (Zhang et al. 2010). Radish is a preventive and cure for stone (in the bladder or kidney) (Abdou et al. 1972). It cures readily bronchial troubles and whooping cough (so common among infants in the East). Radish is reputed to be highly diuretic. Radish is a cruciferous vegetable that has been traditionally used in South Asia for different gastrointestinal, gall bladder and hepatic diseases (Ghayur and Gilani 2012). In Mexico, black radish is employed for the treatment of gallstones and for decreasing lipid serum levels (Castro-Torres et al. 2012, 2014).

Dried ripe radish seed (Raphani Semen) is listed in Pharmacopoeia of the People's Republic of China to be commonly used in TCM for promoting digestion, relieving distension, directing 'Qi' downwards and dissipating phlegm (Chinese Pharmacopoeia Commission 2010; Tan et al. 2005). Raphani Semen is traditionally used to treat food dyspeptic retention, distending pain in the epigastrium and abdomen, constipation, diarrhoea and dysentery, panting and cough with phlegm congestion clinically in combination with other TCM herbs. For example, Raphani Semen is one of the three important ingredients of San-Zi-Yang-Qin-Tang, which is a common TCM formula for relieving cough and asthma, dissipating phlegm and promoting digestion. Radish root has been used as a traditional antimigraine drug in China for hundreds of years (Wu et al. 2014).

Other Uses

Raphanus sativus root was found to have potential in removal of phenolic compounds from phenol-contaminated water (Naghibi et al. 2003). Sliced radish or its juice was added separately as enzyme source to phenol solution, and after 3 hours, more than 90 % of phenol were removed in both cases.

Domingos et al. (2008) employed response surface methodology (RSM) to determine the optimum condition for the ethanolysis of *R. sativus* crude oil. Three process variables were evaluated at two levels (2(3) experimental design): the ethanol–oil molar ratio (6:1 and 12:1), the catalyst concentration in relation to oil mass (0.4 and 0.8 wt.% NaOH) and the alcoholysis temperature (45 and 65 °C). Radish press cake, a solid residue from biodiesel processing, could be used to produce adsorbents by microwave thermal activation for the removal of cationic dyes from wastewaters (Nunes et al. 2011). Both the removal efficiency and the removal capacity decreased with an increase in temperature, pointing towards the exothermic nature of the removal process.

Karri and Bharadwaja (2013) linked two plant defensins, namely, *Trigonella foenum-graecum* defensin 2 (Tfgd2) and *Raphanus sativus* antifungal protein 2 (Rs-AFP2) genes, by a linker peptide sequence (occurring in the seeds of *Impatiens balsamina*) and made into a single-fusion gene construct. This method produced biologically active recombinant His6-tagged fusion protein, which exhibited potent antifungal action towards the plant pathogenic fungi (*Botrytis cinerea*, *Fusarium moniliforme*, *Fusarium oxysporum*, *Phaeoisariopsis personata* and *Rhizoctonia solani* along with an oomycete pathogen *Phytophthora parasitica* var. *nicotianae*) at lower concentrations under in-vitro conditions. This strategy of combining activity of two defensin genes into a single-fusion gene may have promising utility for biotechnological applications.

Comments

Radish plants are propagated primarily from seeds.

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Codonopsis javanica

Scientific Name

***Codonopsis javanica* (Blume) Hook.f. & Thomson**

Synonyms

Campanula javanica (Blume) D. Dietr., *Campanumoea javanica* Blume basionym, *Codonopsis javanica* subsp. *javanica* (Blume) Miq.

Family

Campanulaceae

Common/English Names

Bastard ginseng, Bellflower, Bonnet Flower, Javanese Bluebell

Vernacular Names

Chinese: Dǎngshēn, Jin Qian Bao, Tu Dang Shen
Laos: Man Kha Kai
Vietnam: Dàng Sâm, Cây Dùi Gà, Man Rày Cay (Tay), Co Nhà Dòi (Thai), Cang Hô (H'mông)

Origin/Distribution

E. Asia – subtropical to temperate areas in China Japan, Vietnam, Laos, northern Thailand, Myanmar to Nepal, Bhutan, North east India. In China it is found up to 2,400 m altitude in Anhui, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangxi, Sichuan, Yunnan, Zhejiang and also in Taiwan. In Vietnam it occurs in the mountainous areas of 14 provinces of North Vietnam, particularly in Cao Bang, Lang Son, Lao Cai, Ha Giang, Lai Chau and Son La at altitudes of 500–1,600 m and in the highland in South Vietnam Lam Dong, Kon Tum and Quang Nam at an elevation of 1,500 m.

Agroecology

A cool climate species, hygrophilous and partially shade enduring. Optimum temperature for growth and development and is 18–20 °C but will tolerate temperatures up to 30 °C and low temperatures. It requires an annual mean precipitation of 1,500 mm. It refers well-drained, friable,

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fertile soil rich in humus. It grows wild in meadows, by streams and forest edge in mountainous areas. It grows well on sloping hillside and upland fields.

Edible Plant Parts and Uses

Codonopsis javanica or *Dang Sam* has edible fruit and roots, and the leaves can be used for soup and fried food (Anonymous 2013). Dried roots are used in a special herbal *Dang Sam* chicken soup.

Botany

A deciduous, slender, perennial twining herb that grows to 1.0 m high by 0.5 m wide (Plate 1) with cylindrical tuberous roots reaching 2 cm diameter (Plates 2 and 3). All parts of the plant have milky latex. Stems are greenish and often tinted purplish. Leaves are pale green, 3–8 cm by 2–4 cm, opposite, cordate, margins entire wavy or slightly denticulate. Flower solitary, axillary, with five-toothed calyx and campanulate corolla, ivory yellow and purple veined inside. Five stamens; stigma 4 or 5 fid. Capsule globose, 1–2 cm diameter, with persistent calyx, reddish violet when ripe with numerous lustrous, yellowish, reticulate textured seeds.

Plate 1 Twining dang sam plant

Plate 2 Dried dang sam roots

Plate 3 Close-up of dried dang sam roots

Nutritive/Medicinal Properties

The root was reported to contain an essential oil, glucose, fatty substances, the glucoside scutellarin and a small amount of alkaloids (Nguyen and Doan 1989). The presence of quaternary

ammonium alkaloids codotubulosines A and B, adenosine and 5-(hydroxymethyl)furfural in the roots of *C. javanica* was determined using nuclear magnetic resonance (Li et al. 2009).

Antidiabetic Activity

Studies found that *C. javanica* treatment of fructose-treated rats significantly improved significantly attenuated the hyperinsulinaemia with correspondingly improved glucose tolerance and antioxidant enzyme activities, including superoxide dismutase, glutathione peroxidase and glutathione reductase in the liver (Chen et al. 2013).

The root contains an essential oil, glucose, fatty substances, the glucoside scutellarin and a small amount of alkaloids.

Neuroprotective Activity

Polysaccharides from *C. javanica* were found to have a protective effect on cerebral ischemia–reperfusion injury in mice (Zhang et al. 2011). The polysaccharides alleviated ischemic–reperfusion injuries of neurons in hippocampus CA1 and reduced the brain tissue content of malondialdehyde and nitric oxide, but had no significant effect on superoxide dismutase (SOD), glutathione activity. Its neuroprotective activity may be related to neurotrophic, antioxidant, metabolic control, as well as reduced acetylcholinesterase activity.

Insecticidal Activity

Studies reported that an aqueous extract of roots of *Codonopsis javanica* displayed significant inhibitory activity against the pupae of *Aedes albopictus*, Asian tiger mosquito vector of dengue fever with 75 % mortality both at 12.79 % and 6.39 % concentration of the decoction but poor or little activity against the larvae (Macchioni et al. 2004).

Traditional Medicinal Uses

Codonopsis javanica roots are pounded and liquid drunk to overcome vitamin deficiency and help new mother bring on milk by Akha hill tribals in Northern Thailand (Anderson 1986). The root is used in the treatment of a wide range of conditions, including general debility, fatigue, anaemia, jaundice, dyspepsia, diarrhoea, nephritis, haemorrhoids, oedema and diseases of the lymphatic system (Nguyen and Doan 1989). In Vietnam, *Dang Sam* root is employed in treating digestive and respiratory disorders, anorexia, diarrhoea, fatigue, thirst, general debility or senility after prolonged illness, haemorrhoids, uterine prolapse, metrorrhagia, menorrhagia, anaemia, jaundice, leucocytosis, nephritis, albuminuria and painful oedema in the legs (Le and Nguyen 1999). It is also used as gastric tonic, diuretic, antitussive and expectorant. *Dang Sam* mixed with other herbs are used to treat cough, tuberculosis, lumbago and arthralgia micturition and as general tonic. In Vietnam, the root decoction is used in traditional medicine as tonic and for treating leukaemia, inflammation and hepatitis (Ueda et al. 2002).

Other Uses

Dried roots are used principally for medicine. The Xo Dang people of Tu Mo Rong District in the Central Highlands province of Kon Tum in Vietnam can make easy money from farming *Dang Sam* (a kind of "wide ginseng") in their gardens (Anonymous 2013).

Comments

The plant is usually propagated from seeds, and being a twining climber, support frames or live supports (trees) should be provided.

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Codonopsis lanceolata

Scientific Name

***Codonopsis lanceolata* (Siebold. & Zucc.) Benth. & Hook.f. ex Trautv.**

Synonyms

Campanumoea japonica Sieb. ex Morr., *Campanumoea lanceolata* Siebold & Zucc. basionym, *Codonopsis bodinieri* Lev., *Codonopsis lanceolata* var. *amurae* T. Koyama, *Codonopsis lanceolata* var. *emaculata* Honda, *Codonopsis lanceolata* f. *emaculata* (Honda) H. Hara, *Codonopsis ussuriensis* f. *viridiflora* J. Ohara, *Codonopsis yesoensis* Nakai, *Glosocomia hortensis* Rupr., *Glosocomia lanceolata* (Siebold & Zucc.) Rupr.

Family

Campanulaceae

Common Names

Bonnet Bell Flower, Lance Asia Bell, Todok

Vernacular Names

Chinese: Shen hai lou, Yang Ru
Eastonian: Süstjas väänkellukas
Korean: Deodeok
Japanese: Tsuru-ninjin
Swedish: prickig porslinsklocka

Origin/Distribution

The species is native to northeast China (Anhui, Fujian, Hebei, Henan, Hubei, Hunan, Jiangsu, Shandong, Shanxi, Zhejiang), Eastern Russia, Korea and Japan.

Agroecology

The plant flourishes in a cold temperate area, on well-drained sandy to loamy, acid to near neutral soils (pH 4.8–6.4) in full sun or partial shade but is frost intolerant. In its native range it grows in thin thickets on hill and mountain slopes and forest margins, shrublands, broad-leaved forests subalpine or mountain forest from 200–1,500 m.

Edible Plant Parts and Uses

Codonopsis lanceolata is equally well known as a culinary and medicinal herb in Korea. The thick tuberous roots are eaten raw or cooked, roasted, dried and sliced or pan-fried. The roots are used in Korean salads, cold soups, pan-fried, as dried or fried vegetables and as vegetables soaked in

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Korean sauces or as mixed vegetables with spices (Kim et al. 2006b). Roots are eaten as a tonic when boiled with chicken and old ginseng roots. They are used as health food when preserved in alcohol. Roots are also used to prepare *Codonopsis* wine (light yellow coloured wine) by immersing the roots in *soju* (sweet potato liquor) and consumed for health reasons. Young shoots or leaves are parboiled to make seasoned vegetables or used in soups. The deodeok roots are used in Korean dishes such as *deodeok jeon*, *deodeok-saengchae*, *changui* and *namul*. *Saengchae* is a kind of salad dish except it is seasoned with hot chilli pepper, salt, garlic and green onion. Sometimes, soy sauce is used instead of hot chilli pepper. *Namul* is a variety of steamed vegetables seasoned with hot pepper, garlic, green onion, salt and sesame or perilla oil. Typical vegetables include spinach, daikon, royal fern, bracken, zucchini, mung bean sprouts, *deodeok*, bamboo shoots, etc. *Codonopsis* roots are also an ingredient of *deodeok gui* – root marinated in *gochujang* sauce and grilled over charcoal. Other main ingredients include chicken, liver, beef, fish, mushrooms and vegetables like *dureup* (young shoots of *Aralia elata*). Another popular dish is *Changui*: cold roast of liver and deodeok root. *Deodeok* is also made into *deodeok kimchi*. Its leaves are also edible.

Botany

The plant is a perennial, herbaceous, twining vine up to 1.5–2 m in length, with milky sap, and glabrous. The tap root thickened, fusiform, 10–20 cm long, 1–4 cm in diameter (Plate 1). Leaves are small, alternate on the long main stem, two to four opposite or in a whorl towards the apex of branches. Leaf lamina is rhombic-ovate or narrowly ovate to elliptic, 3–10 cm long and 1.3–4.5 cm wide, apex acute or obtuse, base cuneate, entire or very remotely serrate; petiole 1–5 mm long. Leaves are green on the upper surface and whitish on the lower surface. Flowers are solitary or in pairs, terminal on branches; pedicels 1–9 cm long; calyx tube is about 1 mm long, adnate to middle of ovary, with five ovate–triangular lobes, 1.3–3 cm long. The corolla is campanulate (bell shaped), 2–4 cm long, 2–3.5 in diameter, five deltoid lobes, greenish yellow outside, dark purple patches or stripes inside; stamens 5; ovary half-inferior. Fruit is a cone-shaped capsule, 2–2.5 cm in diameter with numerous winged, brown, ellipsoid seeds.

Plate 1 Tuberous deodeok roots

Nutritive/Medicinal Properties

Root Phytochemicals

The roots were found to contain α-spinasterol, Δ^7-stigmasterol, oleanolic acid, echinocystic acid and an unidentified triterpene acid (Yang et al. 1975). Four β-carboline alkaloids are isolated from the roots: norharman, perlolyrine, 1-carbomethoxy-b-carboline and N_9-formylharman (Chang et al. 1986).

Colonoside B was isolated as the main triterpene glycoside form *C. lanceolata* (Alad'ina et al. 1988). Its aglycone was echinocystic acid and the carbohydrate moiety consisted of D-glucose, D-xylose, L-rhamnose, L-arabinose and D-glucuronic acid residues. Its structure was elucidated as echinocystic acid 3-*O*-β-D-glucopyranuronoside28-*O*-[*O*-β-D-xylopyranosyl-(1→4)-*O*-α-L-rhamnopyranosyl-(1→4)-*O*-β-D-glucopyranosyl-(1→2)-α-L-arabinopyranoside] (Alad'ina et al. 1989).

The roots of *Codonopsis* species including *C. lanceolata* were found to contain hydrophobic constituents β-Sitosterol, α-spinasterol and

taraxerol (Wang et al. 1995). From the roots were isolated four compounds, identified as shikimic acid, succinic acid, syringaresinol and tectorigenin-7-glucoside (Mao et al. 2000). 1, 2, 3, 4-tetrahydro-β-carboline-3-carboxylic acid (0.0012 %) was isolated from the roots and found to be adequate as an analytical marker for the plant (Yoo et al. 2002). Total ash content in the roots was 5.0 % and loss on drying was 11.9 %. A saponin named codonoposide was isolated from *Codonopsis lanceolata* roots and characterised as 3-*O*-[β-D-xylopyranosyl(1→3)-β-D-glucuronopyranosyl]-3β,16α-dihydroxyolean-28-oic acid 28-*O*-[β-D-xylopyranosyl (1→3)-α-L-rhamnopyranosyl (1→2)-α-L-arabinopyranosyl] ester (Lee et al. 2002). Complete hydrolysis of codonoposide produced a sapogenin (1a), and the partial hydrolysis and further isolation afforded two prosapogenins (1b, 1c). The structures of 1a, 1b and 1c were found to be 3β, 16α-dihydroxyolean-28-oic acid (echinocystic acid), 3-*O*-β-D-glucuronopyranoside of echinocystic acid and 3-*O*-β-D-xylopyranosyl (1–3)-β-D-glucuronopyranoside of echinocystic acid. Jung et al. (2006) isolated tangshenoside and β-adenosine from the roots. A triterpenoid saponin, named codonolaside V, was isolated from the root (Yuan and Liang 2006; Zhang et al. 2009). Two unknown compounds 10 and 11 were proposed to be asterogenic acid derivatives containing uronic acid at the C-3 position and a trisaccharide (two pentoses and deoxyhexose) and a disaccharide (pentose and deoxyhexose), respectively, at the C-28 position. Two triterpenoid saponins named codonolaside I and codonolaside II were isolated from the ethanol root extract (Li et al. 2007). Their structures were determined to be 3-*O*-[β-D-xylopyranosyl(1→3)-(6′-*O*-methyl)-β-D-glucuronopyranosyl]-3β, 16α-dihydroxyolean-12-ene-28-oic acid 28-*O*-[β-D-xylopyranosyl (1→4)-α-L-rhamnopyranosyl (1→2)-α-L-arabinopyranosyl] ester and 3β, 16α-dihydroxyolean-12-ene-28-oic acid 28-*O*-[β-D-xylopyranosyl (1→3)-β-D-xylopyranosyl (1→4)-α-L-rhamnopyranosyl (1→2)-α-L-arabinopyranosyl] ester, respectively.

Bioactive constituents of the polar fraction of the roots of *C. lanceolata* included six triterpene saponins, lancemasides B, C, D, E, F and G, along with the known saponin lancemaside A and phenylpropanoid glycosides tangshenoside I, tangshenoside II and syringin (Ushijima et al. 2008). Compound 11 was identified as tryptophan. Hot water extraction of *C. lanceolata* roots yielded saponins lancemaside A, foetidissimoside A and astersaponin Hb in their pure forms (Shirota et al. 2008). Six triterpenoid saponins, including a new compound named codonolaside III, were isolated from *Codonopsis lanceolata* roots of (Xu et al. 2008a). The structure of codonolaside III was elucidated as 3-*O*-[β-D-xylopyranosyl-(1→3)-β-D-glucuronopyranosyl]-3β,16α-dihydroxyolean-12-ene-28-oic acid 28-*O*-[β-D-xylopyranosyl-(1→4)-α-L-rhamnpyranosyl-(1→2)][β-D-glucopyranosyl-(1→4)]-α-L-arabinopyranosyl ester. Seven 3, 28-bidesmosidic triterpenoid saponins were identified in the roots of *Codonopsis lanceolata*: lancemaside A, lancemaside B, lancemaside C, lancemaside E, lancemaside G, foetidissimoside A and aster saponin Hb (Ichikawa et al. 2008, 2009). The overall recoveries of all saponins were 92–116 %. Lancemaside A was the most abundant saponin in the root samples from Korea, ranging from 2.65 to 3.64 mg/g dry root. However, the maximum content of lancemaside A among Japanese samples was 0.101 mg/g dry root.

The presence of quaternary ammonium alkaloids codotubulosine A and B, adenosine and 5-(hydroxymethyl)furfural in the roots of *C. lanceolata* was determined using nuclear magnetic resonance (Li et al. 2009). Three benzofuranylpropanoids, lanceolunes A–C, were isolated from the roots of *Codonopsis lanceolata* (Hu et al. 2012). A symmetrical phenylpropanoid glycoside, tangshenoside VIII, together with six known tangshenosides were isolated from the roots (Ren et al. 2013). A new cerebroside, namely, codonocerebroside A and lobetyolin were isolated from the roots (Zhao et al. 2013).

A total of 50 components were identified in the volatile oil of *Codonopsis lanceolata* root including 16 terpene and terpene alcohols, 13 hydrocarbons, 5 alcohols, 6 aldehyde and ketones, 6 acids, 2 esters and 2 miscellaneous components (Park et al. 1989a, b). The major components were *trans*-2-hexen-l-ol (29.4 %of total volatile oil), *trans*-2-hexenal (24.9 %),

n-hexanol (19.8 %), *n*-hexanal (7.3 %) and *cis-3*-hexen-l-ol (5.6 %). Thirty-five volatile flavour components were identified from *C. lanceolata* by GC-MS (gas chromatography–mass spectrometry) (Kim et al. 1992). *Trans*-2-hexenal, *cis*-3-hexen-l-ol, *trans*-2-hexen-l-ol and n-hexanol were considered key components of the green note, while 1-octen-3-ol is the component of the fresh note. Esters, including amyl propionate, appeared to be responsible for the sweet note characteristic of *C. lanceolata*. The other compounds identified included 2-methyl octane, nitrocyclohexane, 3-methyl-2-heptanol, 4-carene, butyl butyrate, 1-8-cineole, phenylacetaldehyde, limonene, 2-ethyl hexanol, 2,9-dimethyl decane, 2-methyl dodecane, linaly isobutyrate, 2-methyl tridecane, 2-octenal, 2,3-decadienal, 3-dodecanol, citronellyl acetate, *cis*-3-hexenyl caproate, 3-decen-1-ol, humulene, octadecyl benzene, hexadecanoic acid, 9-octadecenal, eicosane, octadecanamide, tetracosane, 1, 2-diisoctyl benzenedicarboxylic acid, hexacosane and heptacosane.

Six compounds were isolated from the plant and identified as syringin, shikimic acid, friedelin, α-spinasterol, stigmasterol and stigmasta-7-dien-3β-ol (Wang et al. 2011b). Transgenic hairy roots of *C. lanceolata* were found to richer in triterpenoids (lancemaside A, foetidissimoside A and aster saponin Hb) than non-transformed roots (Kim et al. 2011). Transgenic plants regenerated from the hairy roots via somatic embryogenesis were found to contain plants having higher triterpenoid levels than wild-type plants. They showed phenotypic alterations such as shortened shoots and an increased number of axillary buds and adventitious roots.

C. lanceolata roots were found to be rich in polysaccharides (Sun 2007). The polysaccharide content was 12.45 %, and the rate of recovery was 99.12 %.

Zhou et al. (2010) found the content of polysaccharides in *C. lanceolata* root from Mount Taishan was highest in 4-year-old plants. The contents of polysaccharide in 2-year-old, 3-year-old and 4-year-old plants were 8.82 %, 10.47 % and 11.32 %, respectively. The average recovery rate was 96.09 %. Zhu et al. (2014) found that the content of triterpene decreases as the plant aged, but the relative content of saccharides initially increased and decreased significantly afterwards. Specifically, the content of polysaccharides accumulated in the root of 2-year-old plant was the lowest, 4-years-old was the highest, and then the content decreased gradually. Sixteen kinds of amino acids were identified in *Codonopsis lanceolata* comprised of 5.70 % hydrolysed amino acids and 4.17 % free amino acids (Xu et al. 2008b).

Other Plant Parts Phytochemicals

Three flavonoids, namely, luteolin, luteolin 5-*O*-β-D-glucopyranoside and luteolin 7-*O*-β-D-glucopyranoside, were isolated from the leaves (Whang et al. 1994). The content of tangshenoside I and saponins (tentatively named saponins A and B) in the parent plants and in the regenerated tissue cultured plants were almost the same (Isoda et al. 1995). A cDNA clone containing a fructose-1, 6-bisphosphate aldolase (ALD) gene, and encoding a precursor protein of 358 amino acid residues, designated ClAldC, was isolated from *Codonopsis lanceolata* (Purev et al. 2008).

The application of a fermentation process was found to effectively improve the biological and pharmacological activities of high-pressure extraction (HPE) of *C. lanceolata* by increasing the extraction efficacy and inducing probiotic conversion (He et al. 2011b). The results suggest that the combined treatment of HPE and a fermentation process could be used as alternative extraction method over conventional extraction. Compared to conventional extraction without fermentation (6.69 mg GAE/g), the phenol amounts of HPE *Bifidobacterium longum* fermentation (HPE-BF) and HPE *Lactobacillus rhamnosus* fermentation (HPE-LRF) were significantly increased to more than 8 mg GAE/g, while the lowest flavonoid contents were observed for HPE-BLF (0.44 mg RE/mL) and HPE-LRF (0.45 mg RE/mL). Cinnamic acid was the most abundant phenolic acid in the fermented *C. lanceolata*.

Antioxidant Activity

The antioxidant activity of the ethanol deodeok extract in soybean oil was significantly stronger compared with that of ginseng in terms of peroxide values and thiobarbituric acid values (Maeng and Park 1991). Antioxidative activities of *Codonopsis lanceolata* were also compared from the electron-donating activity. Fresh *C. lanceolata* had about 70 % of electron-donating activity. Independent of cultivation area, electron-donating activity dropped to 19–74 % (wild *C. lanceolata*) and 27–59 % (cultivated *C. lanceolata*) during 15 days storage. But after 30 days storage, antioxidant activities were higher than 15 days-stored samples or the fresh samples. The results suggested that *Codonopsis lanceolata* could maintain antioxidant activities most strongly with low-density polyethylene (LDPE) film and chilled condition (2–4 °C). The antioxidative activity of *C. lanceolata* was 87 %; addition of salt to *C. lanceolata* did not affect its antioxidative activity (Oh and Kim 2006). In spite of fourfold addition of *Codonopsis lanceolata* to *Cornus officinalis*, the antioxidative activity was conserved at 90 %. Oral administration of the ethanol and aqueous extracts of *C. lanceolata* to mice was found to enhance the antioxidative ability of mice (Wang et al. 2008). The superoxide dismutase, glutathione peroxidase and glutathione levels were enhanced significantly, and the malondialdehyde levels were reduced markedly in the serum, liver and brain homogenate of mice treated with 20 g/kg of both extracts.

The antioxidant activity (1, 1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging) of the leaf and root extracts of transgenic *C. lanceolata* plants was higher (IC_{50} 12–17.33 and 408–524 μg/mL, respectively) than that of control plant leaf and root extracts (18 and 529 μg/mL, respectively) (Ghimire et al. 2011). Analysis of phenolic compounds confirmed an increase in the levels of 12 major phenolic acids and flavonoids in the leaf and root extracts of transgenic plants compared to control plants. Also, the rate of photosynthesis was 48 % higher in transgenic plants than in control plants. Based on these results, the authors suggested that increases in the α-tocopherol level in transgenic *C. lanceolata* plants may result in increases in the photosynthetic performance and antioxidant metabolism of these plants.

High-pressure water treatment was found to have an effect on the extraction of total phenols, flavonoids and phenolic acids from deodeok (He et al. 2011a). The optimising conditions for the pressure-assisted water extraction (PAWE) of *deodeok* as a function of pressure level and extraction time were 385 MPa and 25 minutes for total phenols (633 μg GAE/mL) and 405 MPa and 24 minutes for flavonoids (124 μg RE/mL). The PAWE significantly increased the amount of vanillic acid (41 μg/mL) in *deodeok* extract compared to the conventional extraction (CE, 17 μg/mL). The highest radical scavenging activity (81 %) of *deodeok* extract was achieved at the treatment of 500 MPa and 30 minutes. The application of a fermentation process was found to effectively improve the biological and pharmacological activities of high-pressure extraction (HPE) of *C. lanceolata* by increasing the extraction efficacy and inducing probiotic conversion (He et al. 2011b). The highest DPPH scavenging activities were observed for HPE- *Bifidobacterium longum* fermentation (HPE-BF) and HPE- *Lactobacillus rhamnosus* fermentation (HPE-LRF), with minimum EC_{50} values of 1.26 and 1.18 mg/mL, respectively. The highest amounts of total phenols and flavonoids were observed in chloroform fraction from nonfermented (NF) deodeok (72 and 31 mg RE/g) and *Lactobacillus rhamnosus* fermented (LRF) (79 and 24 mg RE/g) deodeok (Jung et al. 2012b). The ferric reducing antioxidant power (FRAP) values were highly correlated with the DPPH scavenging activity, showing that the highest FRAP values were observed in chloroform fractions from NF (35 mM Fe(II)/g) and LRF (50 mM Fe(II)/g).

The nonfermented *C. lanceolata* samples extracted with high pressure (NF-HPE) had the highest total phenolic content (13.3 mg of GAE/g) (He et al. 2010). The lowest effective concentrations (EC_{50} and $EC_{0.5}$) were 4.55 and 1.76 mg/mL, respectively, for NF-HPE extracts, indicating its highest antioxidant activity.

The total polyphenol content of the heat treatment of fermented *Codonopsis lanceolata* tea for 15 minutes at 200 °C was increased to about 4.5 times of 713.71 mg/100 mL as compared to the control group (Park et al. 2013). From the results of the antioxidant activity test, as both the heating temperature and time increased, the antioxidant activity was increased for DPPH radical scavenging activity, FRAP and reducing its power. In the case of the samples treated with heat for 15 minutes at 200 °C in the DPPH radical scavenging ability, it increased about twice more than control 45.17–85.40 %, and the reducing power and FRAP were increased to approximately two or three times more than the control group.

Anti-inflammatory Activity

Several studies confirmed that the root of *C. lanceolata* had anti-inflammatory activity.

The xylene-induced mouse ear oedema inhibitory effect assay revealed codonolaside and codonolasides I–III as the major anti-inflammatory constituents in *Codonopsis lanceolata* roots (Xu et al. 2008a). Lee et al. (2007) reported that the methanol extracts of fresh leaves or roots of *Codonopsis lanceolata* significantly suppressed the production of proinflammatory mediators, nitric oxide [NO] and tumour necrosis factor [TNF-α]) without altering mRNA levels and also strongly blocked Raf-ERK signalling pathway, which was involved in regulation of post-translational modification of proinflammatory gene products . The expression of interleukin (IL)-3 and IL-6, however, was strongly diminished. The surface levels of the co-stimulatory molecules (CD80 and CD86) of RAW264.7 cells were also enhanced by these extracts. The leaf extract also diminished functional activation and the surface level of dectin-1, but not toll-like receptor (TLR)-2. The results suggested that *Codonopsis lanceolata* may have the ability to modulate macrophage-mediated immune responses, thus contributing to its anti-inflammatory activity. Another study reported that the ethanolic root extract of *Codonopsis lanceolata* displayed significant anti-inflammatory activity of 51.82 % inhibition at 200 mg/kg at 3 hours using the carrageenan-induced rat hind paw oedema model (Li et al. 2007). Further isolation of the extract yielded two triterpenoid saponins, named codonolaside I (1) and codonolaside II (2). Saponin fraction from *Codonopsis lanceolata* was found to have potent anti-inflammatory activity (Byeon et al. 2009a). The fraction suppressed the release of nitric oxide (NO) and tumour necrosis factor (TNF)-α, but not prostaglandin E2 (PGE2). The anti-inflammatory activities on NO production appeared to be due to inhibition of nuclear factor (NF)-κB activation signalling, since it blocked the phosphorylation of inhibitor of kappaB (IkappaB) alpha as well as inducible NO synthase (iNOS) expression. In another study, lancemaside A isolated from *Codonopsis lanceolata* suppressed the production of proinflammatory cytokines, TNF-α and IL-1β, in-vitro and in-vivo (Joh and Kim 2010b). Lancemaside A also down-regulated inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2), as well as the inflammatory mediators, nitric oxide (NO) and PGE(2). Lancemaside A also inhibited the expression of IL-1 receptor-associated kinase-4 (IRAK-4), the phosphorylation of IKK-β and IκB-α, the nuclear translocation of NF-κB and the activation of mitogen-activated protein kinases in LPS-stimulated peritoneal macrophages. Furthermore, lancemaside A inhibited the interaction between LPS and toll-like receptor 4 (TLR4), as well as IRAK-4 expression in peritoneal macrophages. Orally administered lancemaside A, isolated from *C. lanceolata*, was metabolised echinocystic acid which was absorbed into the blood and found to ameliorate lung inflammation in mice and in alveolar macrophages by inhibiting the binding of lipopolysaccharide to toll-like receptor 4 (TLR4) in nuclear factor-kappaB (NF-κB) and mitogen-activated protein kinase (MAPK) pathways (Joh et al. 2012).

Among *Codonopsis lanceolata* rhizome extracts, the BuOH extract inhibited LPS-induced IL-1β, IL-6 and TNF-α expression, as well as NF-κB activation most potently in lipopolysaccharide (LPS)-stimulated peritoneal macrophages (Hyam et al. 2013). BuOH extract also

inhibited colon shortening and myeloperoxidase activity in 2,4,6-trinitrobenzene sulfonic acid (TNBS)-induced colitic mice. Among lancemaside A and its metabolites (lancemaside X, echinocystic acid-3-*O*-β-D-glucopyranoside and echinocystic acid), echinocystic acid inhibited the expression of the proinflammatory cytokines, IL-1β, IL-6 and TNF-α, as well as the phosphorylation of IKKβ and p65 in LPS-stimulated peritoneal macrophages most potently. Echinocystic acid also potently inhibited the binding of LPS to TLR4 on peritoneal macrophages. Lancemaside A and its metabolite, echinocystic acid, inhibited TNBS-induced colonic inflammation, including colon shortening, increased myeloperoxidase activity and proinflammatory cytokine expression and NF-κB activation in mice. Joh et al. (2014) found that topically administered echinocystic acid potently suppressed 12-*O*-tetra decanoylphorbol-13-acetate (TPA)-induced ear swelling in mice. Echinocystic acid also inhibited TPA-induced myeloperoxidase activity, as well as COX-2, iNOS, TNF-α and IL-1β expressions. Echinocystic acid inhibited NF-κB in TPA-treated mouse ears, as well as in lipopolysaccharide-stimulated peritoneal macrophages.

Anticancer Activity

Codonopsis lanceolata had also been reported to possess cytotoxic and antitumour activities. A new saponin named codonoposide (1) from the roots of *Codonopsis lanceolata* on hydrolysis yielded sapogenin (1a) and two prosapogenins (1b, 1c) (Lee et al. 2002). Using MTT (3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide) assay, sapogenin 1a showed marginal cytotoxic activity, whereas prosapogenin1b exhibited more cytotoxicity than sapogenin 1a. The result indicated that glycoside linkage of glucuronic acid at C-3 enhanced the cytotoxicity of sapogenin (1a), and additive glycosylation of xylose to 1b strongly enhanced the cytotoxicity of 3-*O*-monosaccharides (1b). Therefore, true forms of codonoposide for the cytotoxicity were affirmed to be sapogenins or prosapogenins. Studies demonstrated that β-D-xylopyranosyl-(1→3)-β-D-glucuronopyranosyl echinocystic acid (codonoposide 1c), a biologically active compound isolated from the roots of *Codonopsis lanceolata*, was cytotoxic to cancer cells. Additional investigations by Lee et al. (2005) revealed that codonoposide 1c was a potent inducer of apoptosis in HL-60 human promyelocytic leukaemia cells and facilitated its activity via Bid cleavage and translocation to mitochondria, Bax reduction in cytosol, release of cytochrome c and Smac/DIABLO (second mitochondria-derived activator of caspases/direct inhibitor of apoptosis-binding protein with a low isoelectric point) into the cytosol, and subsequently caspase activation, providing a potential mechanism for the cytotoxic activity of codonoposide 1c.

Studies showed that the Fr I fraction containing <1,000 MW of crude polysaccharide from deodeok had the highest total sugar contents, total protein contents, total phenolic compounds content, as well as the greatest growth inhibitory activity against stomach carcinoma SNU-1 and Hela cells, ACE (angiotensin-converting enzyme) inhibitory activity and DPPH (diphenyl picrylhydrazyl) radical scavenging effect (Kim et al. 2006a). The Fr II (1,000 MW<fraction<3,000 MW) fraction exhibited lower physiological activity than Fr I but showed higher activity than those of fraction of above 3,000 MW, but there was no significant ACE inhibitory activity. The fraction Fr III (3,000 MW<fraction <10,000 MW) exhibited the lowest yield, total sugar contents, total protein contents and total phenolic contents, as well as the least growth inhibitory activity against SNU-1, Hela, ACE inhibitory activity and DPPH radical scavenging effect.

The n-butanol fraction of *C. lanceolata* significantly inhibited human colon cancer HT-29 cell growth in a dose- and time-dependent manner by inducing G0/G1 phase arrest and apoptosis (Wang et al. 2011a). The inhibition was associated with intracellular ROS generation and polyamine depletion. The methanol extracts of *Codonopsis lanceolata* inhibited tumour growth of HSC-2 human oral cancer cells by inducing apoptosis (Shin et al. 2012). It also increased Bak protein expression, while Bax, Bcl-XL and Mcl-1 were not affected.

Antimicrobial Activity

The probiotic *Bifidobacterium longum*-fermented *C. lanceolata* samples extracted by high pressure (BLF-HPE) exhibited the highest antimicrobial activity (MIC<14 mg/mL) against *Listeria monocytogenes*, *Staphylococcus aureus*, *Shigella boydii* and *Salmonella typhimurium* (He et al. 2010). The application of a fermentation process was found to effectively improve the biological and pharmacological activities of high-pressure extraction (HPE) of *C. lanceolata* by increasing the extraction efficacy and inducing probiotic conversion (He et al. 2011b). The HPE-*Bifidobacterium longum* fermentation (HPE-BF) and HPE-*Lactobacillus rhamnosus* fermentation (HPE-LRF) samples exhibited the most noticeable antimicrobial activities against *Staphylococcus aureus*, *Listeria monocytogenes*, *Salmonella typhimurium* and *Shigella boydii* (MICs<15 mg/mL). *Staphylococcus aureus* biofilm cells were highly susceptible to chloroform fraction of deodeok, showing 1.8 log reductions (Jung et al. 2012b).

Antimutagenic Activity

The *Bifidobacterium longum*-fermented *C. lanceolata* samples extracted by high pressure (BLF-HPE) and *Lactobacillus rhamnosus*-fermented *C. lanceolata* samples extracted by high pressure (LRF-HPE) exhibited the highest antimutagenic activities in *Salmonella typhimurium* TA 100, which were 82 % and 83 % inhibition, respectively (He et al. 2010).

Adaptogenic Activity

Codonopsis lanceolata root extract and its bioactive constituent lancemaside A were reported to inhibit the reduction of blood testosterone levels induced by immobilisation stress in mice (Sekita et al. 2005). The positive responses of ClAldC (a cDNA clone containing a fructose-1,6-bisphosphate aldolase (ALD) gene isolated from *C. lanceolata*) to the three abiotic stimuli suggested that *C. lanceolata* ClAldC may help to protect against abiotic environmental stresses such as anoxia, chilling and oxidative stress (Purev et al. 2008).

A dehydrin gene designated as ClDhn was isolated from *C. lanceolata* (Pulla et al. 2008). The full-length cDNA of ClDhn was 813 bp and contained a 477 bp open reading frame (ORF) encoding a polypeptide of 159 amino acids. RT-PCR analysis showed that different abiotic stresses such as salt, wounding, chilling and light triggered a significant induction of ClDhn at different time points within 4–48 hours posttreatment. This study revealed that ClDhn assisted *C. lanceolata* in becoming resistant to dehydration.

In the course of the development of new designer foods using the roots of *C. lanceolata*, Japanese scientists found that hot water extracts of *C. lanceolata* recovered decreased testosterone levels in the blood and accelerated the restoration of reproductive dysfunction induced by hyperthermic treatment in male mice (Ushijima et al. 2008). One of the bioactive constituents tangshenoside I accelerated the restoration of reproductive dysfunction induced by hyperthermic treatment in male mice.

The aqueous extract of *C. lanceolata* root at the dose of 20 g/kg reduced the cumulative oxygen consumption at different times and prolonged survival time of mice with hypoxia, the loaded swimming time and the rotational stick endurance time in mice (Wang et al. 2007). In another study, the purified polysaccharide from 4-year-old *C. lanceolata* roots, at the dose of 1.5 g/kg, reduced oxygen consumption and prolonged the survival time of mice in hypoxia condition (Zhao et al. 2011). It also prolonged the loaded swimming time of mice indicating its antifatigue effect.

Hepatoprotective Activity

Han and Cho (1997) found that hepatic cytochrome P450 content and activity of superoxide dismutase in rats were decreased by carbon tetrachloride but was significantly increased by *Codonopsis lanceolata* water extract. Significant

decrease in hepatic xanthine oxidase activity was found in rats treated with *Codonopsis lanceolata* water extract. Contents of glutathione and lipid peroxide and the activity of glutathione peroxidase elevated by carbon tetrachloride were significantly decreased by *Codonopsis lanceolata* water extract. The activities of catalase and glutathione S-transferase were not significantly influenced by *Codonopsis lanceolata* water extract. Studies by Zhang et al. (2007) reported that administration of *C. lanceolata* extract protected against alcohol-induced hepatic injury in mice possibly by enhancing its radical scavenging ability to inhibit lipid peroxidation in mice liver. Superoxide dismutase, glutathione peroxidase activity and selenium levels were significantly higher in extract-treated mice compared to control mice.

Kim et al. (2009) found that the saponin fraction from *Codonopsis lanceolata* exerted a protective effect against water immersion stress-induced liver damage and radical generation. It decreased the elevated levels of serum glutamate-oxaloacetate transaminase and glutamate-pyruvate-transaminase induced by water-immersed stress conditions, and Griess and DPPH assays revealed that Cl-SF significantly suppressed both radical generation in sodium nitroprusside-treated RAW264.7 cells and nitric oxide production in LPS-treated RAW264.7 cells. Among the three different fractions prepared from the *C. lanceolata* root, the methanol extract exhibited the most remarkable attenuation of alcohol-induced fatty liver in mice with respect to various parameters such as hepatic free fatty acid concentration, body weight loss and hepatic accumulations of triglyceride and cholesterol (Cha et al. 2012). The beneficial effects of the extract against alcoholic fatty livers of mice appeared to be with adenosine- and adiponectin-mediated regulation of hepatic steatosis and toll-like receptor (TLR)-mediated modulation of hepatic proinflammatory responses.

In-vivo studies showed that supplementation of *C. lanceolata* root water extract to rats appeared to be protective against alcoholic fatty liver caused by chronic alcohol consumption, through the down-regulation of tumour necrosis factor-α (TNF-α), liver X receptor α (LXRα), sterol regulatory element-binding protein (SREBP)-1c, fatty acid synthase, acetyl-coenzyme A carboxylase α (ACC), stearoyl-coenzyme A desaturase 1, 3-hydroxy-3-methylglutaryl-coenzyme A reductase (HMGR), and low-density lipoprotein receptor (LDLR) genes and by the phosphorylation of phospho-5′-AMP-activated protein kinase (AMPK) α and acetyl-coenzyme A carboxylase α which were implicated in lipid metabolism (Cho et al. 2009).

Neuroprotective Activity

Yoo et al. (2011) found that ethyl acetate extracts of raw and steamed *Codonopsis lanceolata* protected against ischemic damage in gerbil hippocampal CA1 region after an ischemic insult by reducing ischemic neuronal loss potentially by maintaining superoxide dismutase 1 (SOD1) and brain-derived neurotrophic factor (BDNF) immunoreactivity in the ischemic hippocampal CA1 region.

Antihyperlipidaemic/Anti-obesity Activity

Oral administration of *Codonopsis lanceolata* water extract to rats fed a high fat diet significantly reduced the elevated level of serum total lipid, serum triglyceride and total cholesterol (Han et al. 1998). The levels of serum HDL-cholesterol and phospholipid were slightly increased by *C. lanceolata* water extract. Studies showed that fermented milk supplement containing *Codonopsis lanceolata* roots had an antihyperlipidemic effect on the blood lipid profiles in ovariectomised (OVX) rats (Chang and Cheong 2007). Serum triglyceride, total cholesterol and LDL-cholesterol levels in ovariectomised Sprague-Dawley female rats fed fermented milk supplement containing *C. lanceolata* (CL) roots) were significantly lower than the OVX group. The ratio of HDL-cholesterol to

total cholesterol was significantly higher and the ratio of LDL-cholesterol to HDL-cholesterol was significantly lower.

Animal studies by Choi et al. (2013) indicated *C. lanceolata* to have great potential as a functional food with anti-obesity effects and as a therapeutic alternative in the treatment of obesity. The body weight gains of rats administered high fat diet (HFD) + *C. lanceolata* were lower than those of the rats fed with only the HFD. Additionally, the weight of adipose pads and the serum levels of triglycerides, total cholesterol and low-density lipoprotein cholesterol in the group administered HFDL + *C. lanceolata* were significantly lower than in the HFD group. Treatment of 3T3-L1 cells with *C. lanceolata* inhibited lipid accumulation and expression of C/EBPα and PPARγ.

Antidiabetic Activity

The α-glucosidase inhibitory activities of *Codonopsis lanceolata* was 25 % and the addition of salt slightly decreased its α-glucosidase inhibitory activity (Oh and Kim 2006). On addition of *Cornus officinalis* to *Codonopsis lanceolata*, the α-glucosidase inhibitory activities of the resulting mixture was highly increased. Tangshenoside and β-adenosine were isolated as α-glucosidase inhibitors from the roots (Jung et al. 2006). They exerted weak α-glucosidase inhibitory activities in-vitro with IC_{50} of 1.4 and 9.3 mM, respectively. Administration of *C. lanceolata* root polysaccharides to alloxan-induced diabetic mice significantly reduced the level of fasting plasma glucose and malondialdehyde content; and improved antioxidant activity by increasing serum and pancreatic gland superoxide dismutase activity (Zhang et al. 2010). In a subsequent study, they reported that *C. lanceolata* root polysaccharides decreased the level of fasting blood glucose in diabetic mellitus rats, and significantly improved cellular immune function (Zhang et al. 2012). Also, thymus index was enhanced significantly and lymphocyte proliferation stimulated.

The application of a fermentation process was found to effectively improve the biological and pharmacological activities of high-pressure extraction (HPE) of *C. lanceolata* by increasing the extraction efficacy and inducing probiotic conversion (He et al. 2011b). The HPE-*Bifidobacterium longum* fermentation (HPE-BF) and HPE-*Lactobacillus rhamnosus* fermentation (HPE-LRF) samples effectively inhibited α-glucosidase and tyrosinase activities and potentially improved a scopolamine-induced memory deficit in mice.

Anti-colitic Activity

Oral administration of lancemaside A (10 and 20 mg/kg), from *C. lanceolata*, inhibited colon shortening and myeloperoxidase activity in 2, 4, 6-trinitrobenzene sulfonic acid (TNBS)-induced colitic mice and also decreased colonic expression of interleukin IL-1beta, IL-6 and TNF-alpha (Joh et al. 2010). Lancemaside A inhibited NF-kappaB activation induced by TNBS, as well as the expression of cyclooxygenase 2 and TLR-4. Lancemaside A also reduced the activity of intestinal bacterial β-glucuronidase that was induced by TNBS.

Cognitive Enhancing Activity

Han et al. (1999) found that old mice ingesting *C. lanceolata* extract, 4 and 8 g/kg, learned faster that those drinking water. Lipid peroxide level in red blood cells were decreased and superoxide dismutase increased by ingestion of the extract.

Lancemaside A, active ingredient in *C. lanceolata* rhizome, orally administered to mice 5 hours before scopolamine treatment. Significantly reversed scopolamine-induced memory and learning deficits (Jung et al. 2012a). Lancemaside A and its metabolite echinocystic acid which was absorbed into the blood significantly reversed scopolamine-induced memory and learning deficits on the Y-maze and Morris water maze tasks. Echinocystic acid more potently reversed it than lancemaside A. Both inhibited AChE activity and

increased the expression of brain-derived neurotrophic factor (BDNF) and phosphorylated cAMP response element-binding protein (p-CREB). Fermented *C. lanceolata* extract (500 mg/kg body weight, p.o.) significantly shortened the escape latency times that were increased by scopolamine on the fourth day of trial sessions in the Morris water maze task (Weon et al. 2013a, b). Additionally, it exerted longer step-through latency times than those of the scopolamine-treated group in the passive avoidance test. Steamed and fermented *C. lanceolata* extract showed a relative protection ratio of 59.62 % at 500 μg/mL on glutamate-induced neurocytotoxicity in HT22 cells.

Anticholinesterase Activity

The highest anticholinesterase activity was observed in chloroform and ethyl acetate fractions from *Lactobacillus rhamnosus* fermented *deodeok* (1.5 mg/mL < EC_{50} <2.5 mg/mL) (Jung et al. 2012b).

Fibrinolytic/Blood Flow Stimulating Activity

The fibrinolytic activity of *Codonopsis lanceolata* was 0.78 plasmin unit/mL and addition of salt decreased its fibrinolytic activity (Oh and Kim 2006). A mixture (3:1) of *Codonopsis lanceolata* and *Cornus officinalis* exhibited a 21 % increase in activity. Fibrinolytic activity of fresh *Codonopsis lanceolata* cultivated in the mountain or field was 0.8 unit (plasmin unit/mL) or 7.3 units, respectively (Kim et al. 2005). In descending order, the activities of wild *Codonopsis lanceolata* stored for 15 days were as followed; low-density polyethylene (LDPE)-RE (refrigerated 2–4 °C) (0.70 unit), woven polypropylene (WP)-RO (room temperature 18–20 °C) (0.52 unit), WP-RE (0.45 unit) and LDPE-RO (0.30 unit). After 30 days, fibrinolytic activities of them decreased to 0.47 unit (LDPE-RE), 0.28 unit (WP-RO), 0.21 unit (WP-RE) and 0.30 unit (LDPE-RO). Considering from the point of fibrinolytic activity, the optimal storage condition of wild *C. lanceolata* was packing with LDPE film and storing at 4 °C. The fibrinolytic activities of 30-day-stored samples were maintained better than the wild *C. lanceolata*. Fibrinolytic activity of wild *C. lanceolata* was increased by heating for 5 minutes at 100 °C and decreased by addition of salt.

Animal studies by Xu et al. (2008a) found that administration of the alcohol extract of *C. lanceolata* exhibited effects of invigorating energy, stimulating blood flow and resolving blood stasis in rats and anti-ageing in mice. The extract enhanced red blood cell electrodeposition time and decreased significantly whole blood viscosity (high sheer, middle sheer, low sheer), plasma viscosity, aggregation indices of red blood cells and packed red blood cells in rats with Qi deficiency and blood stasis syndrome. The extract at high dose extended the time of antianoxia significantly on the 7th day and 14th day, while the group receiving low dose of extract extended the time of antianoxia significantly on the 14th day. Both of the group of high-dose and low-dose extract increased thymus weights of mice significantly on the 7th day and 14th day and spleen weights of mice on the 14th day.

Immunomodulatory Activity

Codonopsis lanceolata water extract increased the proliferation of thymocytes in-vivo and accelerated the activation of helper T cells in thymocytes (Suh 1996; Kim et al. 1996). The extract inhibited the production of nitric oxide from peritoneal macrophages and increased the phagocytosis of human polymorphonuclear cells. The results suggested that *Codonopsis lanceolata* had immunoregulatory action in-vivo.

Oral administration of the active component (MW 3,500 above) separated from the water fraction of *C. lanceolata* root methanol extract to mice for 7 days enhanced the proliferation of thymocyte, the population of CD^4–$CD8^+$single-positive cells and phagocytic activity in macrophage (Suh and Eun 1998). Studies showed that oral administration of *C. lanceolata* water extract for 4 weeks to old BALB/c mice significantly enhanced immune function by increasing the splenocyte proliferation and enhance the

immune function through regulating cytokine production capacity (Ryu et al. 2009). Cytokine production was more significantly enhanced at the lower supplementation (50 mg/kg BW) group rather than at the higher concentration (500 mg/kg BW) compared to the control group.

Results of studies by Byeon et al. (2009b) suggested that the ethnopharmacological role of *Codonopsis lanceolata* on the recovery of blood loss and spleen QI may be due to its upregulatory effect of granulocyte–macrophage-colony stimulating factor (GM-CSF) expression via activating relevant signalling cascades.

Androgen Deficiency Alleviation Activity

Root extract of *C. lanceolata* had been reported to inhibit the reduction of blood testosterone levels induced by psychological stress in mice (Sekita et al. 2005). Lancemaside A, its active constituent, had been reported to contribute to the recovery of decreased testosterone levels in the blood. A supplement containing the root extracts of *C. lanceolata* was found to alleviate partial androgen deficiency of the ageing male (PADAM)-like symptoms (Morales and Lunenfeld 2002; Ushijima et al. 2007).

Pharmacokinetic Studies

When lancemaside A (3-*O*-β-D-glucuronopyranosyl-3B, 16α-dihydroxyolean-12-en-28-oic acid 28-*O*-β-D-xylopyranosyl(1→3)-β-D-xylopyranosyl-(1→4)-α-L-rhamnopyranosyl-(1→2)-α-L-arabinopyranosyl ester) (60 mg/kg) was orally administered to mice, echinocystic acid was detected in the blood (Joh and Kim 2010a). Orally administered lancemaside A was metabolised to lancemaside X (3β, 16α-dihydroxyolean-12-en-28-oic acid 28-*O*-β-D-xylopyranosyl(1→3)-β-D-xylopyranosyl-(1→4)-α-L-rhamnopyranosyl-(1→2)-α-L-arabinopyranosyl ester) by intestinal microflora in mice, which was metabolised to echinocystic acid by intestinal microflora and/or intestinal tissues. Human intestinal microflora also metabolised lancemaside A to echinocystic acid via lancemaside X. In another study, after oral administration of lancemaside A at 100 mg/kg body weight, the unmetabolised compound appeared rapidly in murine plasma (t_{max}=0.5 hour) (Komoto et al. 2010). Lancemaside A had a low bioavailability (1.1 %) because of its metabolism by intestinal bacteria and its poor absorption in the gastrointestinal tract. In addition, four metabolites were identified from the cecum of mice after oral administration of lancemaside A: codonolaside II, echinocystic acid, echinocystic acid 28-*O*-β-D-xylopyranosyl-(1→4)-α-L-rhamnopyranosyl-(→2)-α-L-arabinopyranosyl ester and echinocystic acid 28-*O*-α-L-rhamnopyranosyl-(→2)-α-L-arabinopyranosyl ester. Among these metabolites, codonolaside II and echinocystic acid were detected in plasma, and their t_{max} values were 4 and 8 hours, respectively.

Allergic Activity

A case of serious anaphylactic reaction in an 18-year-old student following ingestion of *C. lanceolata* roots was confirmed (Hur et al. 2008). Severe systemic reactions including hypotension (90/40 mmHg), chest discomfort, dyspnoea, diaphoresis and generalised urticaria developed within 30 minutes following ingestion of 20 g of *C. lanceolata*. The reaction probably resulted via a direct histamine-releasing mechanism.

Traditional Medicinal Uses

The roots of *C. lanceolata* have been used in traditional medicines as an anti-inflammatory agent and for bronchitis and for cough (Lee et al. 2002; Xu et al. 2008a). In Korea, *deodeok* has been used as a traditional *qi* tonic herb to aid those who are weakened by blood loss or other injury (Byeon et al. 2009b). Weon et al. (2013a, b) reported that *C. lanceolata* has been tradi-

tionally used to treat lung inflammatory diseases, such as asthma, tonsillitis and pharyngitis in Korea. In Korea, the roots are used for coughs, fevers, furuncles, bronchitis, leucorrhoea, and lymph tuberculosis, detoxification, and as expectorant, tonic and for milk reduction (Kim et al. 2006b; Ahn 1998). *Codonopsis lanceolata* has long been used as traditional folk medicine in Korea, Japan and China for the treatment of lung inflammatory diseases (Lee et al. 2007; Hur et al. 2008). *C. lanceolata* root, a traditional Chinese herbal medicine, has a long history in China, and some other Asian countries and is reported to be used to treat lung ailments, rheumatism, menstrual disturbance and bruises with (Zhu et al. 2014). Dried roots of *Codonopsis lanceolata* is used as a tonic in oriental medicine to strengthen Yin and its sap as anti-ageing properties. The root is aphrodisiac, anticancer, depurative, emmenagogue and galactagogue. It has medicinal efficacies for asthma, convulsions, chillness and fever, strengthening respiratory organs' function, tonsillitis, pharyngitis, cough, expectoration, discharge of phlegm, discharge of pus and furuncles. It also has been used to treat oedema, lung abscess, malignant tumour, peptic ulcer and kidney stones. A decoction is used in the treatment of lung abscesses, milk-flow obstruction, amenorrhoea, acute and inflamed boils and abscesses and lymphadenopathy.

Other Uses

Besides being eaten, *deodeok* is widely used as natural herbal medicine in Korea.

Comments

The plant is grown commercially in Hoengseong County and Gangwon Province, South Korea, where it is an important part of the local agriculture.

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Author's Blurb

TK Lim (Tong Kwee Lim) obtained his bachelor's and master's degrees in Agricultural Science from the University of Malaya and his PhD (Botanical Sciences) from the University of Hawaii. He worked in the Agricultural University of Malaysia for 20 years as a Lecturer and Associate Professor; as Principal Horticulturist for 9 years for the Department of Primary Industries and Fisheries, Darwin, Northern Territory; for 6 years as Manager of the Asia and Middle East Team in Plant Biosecurity Australia, Department of Agriculture, Fisheries and Forestry, Australia, and for 4 years as Research Program Manager with the Australian Centre for International Agriculture Research (ACIAR), Department of Foreign Affairs and Trade, Australia, before he retired from public service. He has published over a hundred scientific papers and several books: 'Guava in Malaysia: Production, Pest and Diseases', 'Durian Diseases and Disorders', 'Diseases of Mango in Malaysia'; chapters in books, international refereed journals, conference proceedings (as editor) and technical bulletins in the areas of plant pathology, crop protection, horticulture, agronomy and quarantine science. He was also a reviewer of scientific papers for several international scientific journals. As Principal Horticulturist in Darwin, he and his team were instrumental in establishing the horticultural industry in Northern Territory, Australia, especially on tropical fruit, vegetables, culinary herbs, spices/medicinal herbs and tropical flowers. During his tenure with Plant Biosecurity, he led a team responsible for conducting pest risk analyses and quarantine policy issues dealing with import and export of plants and plant products into and out of Australia from and for the Middle East and Asian region. During his time with ACIAR, he oversaw and managed international research and development programs in plant protection and horticulture, covering a wide array of crops that included fruit, plantation crops, vegetables, culinary and medicinal herbs and spices mainly in southeast Asia and the Pacific. In the course of his four decades of working career, he has travelled extensively worldwide to many countries in South Asia, East Asia, Southeast Asia, Middle East, Europe, the Pacific Islands, USA and England and also throughout Malaysia and Australia. Since his tertiary education days, he always had a strong passion for crops and took an avid interest in edible and medicinal plants. Over the four decades, he has taken several thousands of photographs of common, known and lesser known edible, medicinal and non-medicinal plants; amassed local literature, local indigenous knowledge and books and has developed and established a close rapport with many local researchers, scientists, growers and farmers during the course of his work and travels. All relevant available and up-to-date information collated on more than 1,000 species of edible, medicinal and non-medicinal plants will be provided in a comprehensive reference series fully illustrated with coloured images to help in plant identification. This work will cover scientific names, synonyms, common and vernacular names, origin and distribution, agroecology, edible plant parts and uses, plant habit/description, nutritive and medicinal value, other uses and selected current references. Additional information is provided on the medicinal uses

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and pharmacological properties of plants. This work will be of significant interest to scientists, researchers, practitioners (medical practitioners, pharmacologists, ethnobotanists, horticulturists, food nutritionists, agriculturists, botanists, herbalogists, herbologists, naturalists, conservationists, extension scientists, teachers and lecturers), students and the general public.

Medical Glossary

AAD Allergic airway disease, an inflammatory disorder of the airways caused by allergens.

AAPH 2,2′-azobis (2-amidinopropane) dihydrochloride, a water-soluble azo compound used extensively as a free-radical generator, often in the study of lipid peroxidation and the characterisation of antioxidants.

Abeta aggregation Amyloid beta protein (Abeta) aggregation is associated with Alzheimer's disease (AD); it is a major component of the extracellular plaque found in AD brains.

Abdominal distension Referring to generalised distension of most or all of the abdomen. Also referred to as stomach bloating often caused by a sudden increase in fibre from consumption of vegetables, fruit and beans.

Ablation therapy The destruction of small areas of myocardial tissue, usually by application of electrical or chemical energy in the treatment of some tachyarrhythmias.

Abortifacient A substance that causes or induces abortion.

Abortivum A substance inducing abortion.

Abscess A swollen, infected, inflamed area filled with pus in body tissues.

ABTS 2.2 azinobis-3-ethylhenthiazoline-6-sulfonic acid, a type of mediator in chemical reaction kinetics of specific enzymes.

ACAT Acyl CoA: cholesterol acyltransferase.

ACE See angiotensin-converting enzyme.

ACTH (Adrenocorticotropic hormone) Also known as 'corticotropin', it is a polypeptide tropic hormone produced and secreted by the anterior pituitary gland.

Acetogenins Natural products from the plants of the family Annonaceae, they are very potent inhibitors of the NADH-ubiquinone reductase (Complex I) activity of mammalian mitochondria.

Acetyl-CoA carboxylase (ACC) Enzyme that catalyses the biotin-dependent carboxylation of acetyl-CoA to produce malonyl-CoA.

Acetylcholinesterase (AChE) Is an enzyme that degrades (through its hydrolytic activity) the neurotransmitter acetylcholine, producing choline.

Acne vulga'ris Also known as chronic acne, usually occurring in adolescence, with comedones (blackheads), papules (red pimples), nodules (inflamed acne spots) and pustules (small inflamed pus-filled lesions) on the face, neck and upper part of the trunk.

Acidosis Increased acidity, an excessively acid condition of body fluids.

Acquired immunodeficiency syndrome (AIDS) An epidemic disease caused by an infection by the human immunodeficiency virus (HIV-1, HIV-2), a retrovirus that causes immune system failure and debilitation and is often accompanied by infections such as tuberculosis.

Acridone An organic compound based on the acridine skeleton with a carbonyl group at the 9 position.

ACTH Adrenocorticotropic hormone (or corticotropin), a polypeptide tropic hormone produced and secreted by the anterior pituitary gland. It plays a role in the synthesis and secretion of gluco- and mineralo-corticosteroids and androgenic steroids.

Activating transcription factor (ATF) A protein (gene) that binds to specific DNA sequences regulating the transfer or transcription of information from DNA to mRNA.

Activator protein-1 (AP-1) A heterodimeric protein transcription factor that regulates gene

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expression in response to a variety of stimuli including cytokines, growth factors, stress and bacterial and viral infections. AP-1 in turn regulates a number of cellular processes including differentiation, proliferation and apoptosis.

Actoprotective Increasing the body's physical performance.

Actoprotectors Preparations that increase the mental performance and enhance body stability against physical loads without increasing oxygen consumption. Actoprotectors are regarded as a subclass of adaptogens that hold a significant capacity to increase physical performance.

Acute otitis media (AOM) See otitis media.

Acyl-CoA dehydrogenases A group of enzymes that catalyses the initial step in each cycle of fatty acid β -oxidation in the mitochondria of cells.

Adaptogen A term used by herbalists to refer to a natural herb product that increases the body's resistance to stresses such as trauma, stress and fatigue.

Adaptogenic Increasing the resistance of the body to stress.

Addison's disease Is a rare endocrine disorder. It occurs when the adrenal glands cannot produce sufficient hormones (corticosteroids). It is also known as chronic adrenal insufficiency, hypocortisolism or hypocorticism.

Adenocarcinoma A cancer originating in glandular tissue.

Adenoma A benign tumour from a glandular origin.

Adenoidectomy Surgical removal of the adenoids.

Adenopathy Abnormal enlargement or swelling of the lymph node.

Adenosine receptors A class of purinergic, G-protein-coupled receptors with adenosine as endogenous ligand. In humans, there are four adenosine receptors. A1 and $A2_A$ receptors play roles in the heart, regulating myocardial oxygen consumption and coronary blood flow, while the $A2_A$ receptor also has broader anti-inflammatory effects throughout the body. These two receptors also have important roles in the brain, regulating the release of other neurotransmitters such as dopamine and glutamate, while $A2_B$ and A3 receptors are located mainly peripherally and are involved in inflammation and immune responses.

ADH See alcohol dehydrogenase.

Adipocyte A fat cell involved in the synthesis and storage of fats.

Adipocytokine Bioactive cytokines produced by adipose tissues.

Adiponectin A protein in humans that modulates several physiological processes such as metabolism of glucose and fatty acids and immune responses.

Adipose tissues Body fat, loose connective tissue composed of adipocytes (fat cells).

Adoptogen Containing smooth pro-stressors which reduce reactivity of host defense systems and decrease damaging effects of various stressors due to increased basal level of mediators involved in stress response.

Adrenal glands Star-shaped endocrine glands that sit on top of the kidneys.

Adrenalectomised Having had the adrenal glands surgically removed.

Adrenergic Having to do with adrenaline (epinephrine) and/or noradrenaline (norepinephrine).

Adrenergic receptors A class of G protein-coupled receptors that are targets of the noradrenaline (norepinephrine) and adrenaline (epinephrine).

Adulterant An impure ingredient added into a preparation.

Advanced Glycation End products (AGEs) Resultant products of a chain of chemical reactions after an initial glycation reaction. AGEs may play an important adverse role in the process of atherosclerosis, diabetes, aging and chronic renal failure.

Aegilops An ulcer or fistula in the inner corner of the eye.

Afferent Something that so conducts or carries towards, such as a blood vessel, fibre or nerve.

Agammaglobulinaemia An inherited disorder in which there are very low levels of protective immune proteins called immunoglobulins. *cf.* x-linked agammaglobulinaemia.

Agalactia Lack of milk after parturition (birth).

Age-related macular degeneration (AMD) A medical condition of elderly adults that results in a loss of vision in the center of the visual field (the macula) because of damage to the retina.

Agglutinin A protein substance, such as an antibody, that is capable of causing agglutination (clumping) of a particular antigen.

Agglutination Clumping of particles.

Agonist A drug that binds to a receptor of a cell and triggers a response by the cell.

Ague A fever (such as from malaria) that is marked by paroxysms of chills, fever and sweating and that recurs at regular intervals.

AHR AhR, aryl hydrocarbon receptor, a cytosolic protein transcription factor.

AIDS See acquired immunodeficiency syndrome.

Akathisia A movement disorder in which there is an urge or need to move the legs to stop unpleasant sensations. Also called restless leg syndrome, the disorder is often caused by long-term use of antipsychotic medications.

AKT Serine/threonine kinase (also known as protein kinase B or PKB) plays a critical regulatory role in diverse cellular processes including cancer progression and insulin metabolism.

Akt signaling pathway Akts are protein kinases involved in mammalian cellular signaling that inhibits apoptotic processes.

Akt/FoxO pathway Cellular processes involving Akt and FoxO transcription factors that play a role in angiogenesis and vasculogenesis.

Akt/GSK-3β/eNOS phosphorylation Amplifies serotonin 5-HT2B receptor blockade-mediated anti-hypertrophic effects.

Alanine transaminase (ALT) Also called Serum Glutamic Pyruvate Transaminase (SGPT) or Alanine aminotransferase (ALAT), an enzyme present in hepatocytes (liver cells). When a cell is damaged, it leaks this enzyme into the blood.

ALAT, (Alanine aminotransferase) See alanine transaminase.

Albumin Water-soluble proteins found in egg white, blood serum, milk, various animal tissues and plant juices and tissues.

Albuminaria Excessive amount of albumin in the urine, a symptom of severe kidney disease.

Aldose reductase, aldehyde reductase An enzyme in carbohydrate metabolism that converts glucose to sorbitol.

Alexipharmic An antidote remedy for poison.

Alexiteric A preservative against contagious and infectious diseases and the effects of poisons.

Alcohol dehydrogenase (ADH) An enzyme involved in the breakdown of alcohol.

Algesic Endogenous substances involved in the production of pain that is associated with inflammation, e.g. serotonin, bradykinin and prostaglandins.

Alkaline phosphatase (ALP) An enzyme in the cells lining the biliary ducts of the liver. ALP levels in plasma will rise with large bile duct obstruction, intrahepatic cholestasis or infiltrative diseases of the liver. ALP is also present in bone and placental tissues.

Allergenic Having the properties of an antigen (allergen), immunogenic.

Allergic Pertaining to, caused by, affected with or of the nature of allergy.

Allergic conjunctivitis Inflammation of the tissue lining the eyelids (conjunctiva) due to allergy.

Allergy A hypersensitivity state induced by exposure to a particular antigen (allergen) resulting in harmful immunologic reactions on subsequent exposures. The term is usually used to refer to hypersensitivity to an environmental antigen (atopic allergy or contact dermatitis) or to drug allergy.

Allodynia A painful response to a normally innocuous stimulus.

Allogeneic Cells or tissues which are genetically different because they are derived from separate individuals of the same species. Also refers to a type of immunological reaction that occurs when cells are transplanted into a genetically different recipient.

Allografts Or homografts, a graft between individuals of the same species but of different genotypes.

Alloknesis Itch produced by innocuous mechanical stimulation.

Allostasis The process of achieving stability, or homeostasis, through physiological or behavioural change.

Alopecia Is the loss of hair on the body.

Alopecia areata Type of hair loss that typically causes patches of baldness.

ALP See Alkaline phosphatase.

Alpha-adrenoceptor Receptors postulated to exist on nerve cell membranes of the sympathetic nervous system in order to explain the specificity of certain agents that affect only some sympathetic activities (such as vasoconstriction, relaxation of intestinal muscles and contraction of smooth muscles).

Alpha amylase (α-amylase) A major form of amylase found in humans and other mammals that cleaves alpha bonds of large, alpha-linked

polysaccharides such as starch and glycogen yielding glucose and maltose.

ALT See Alanine transaminase.

Alterative A medication or treatment which gradually induces a change and restores healthy functions without sensible evacuations.

Alveolar macrophage A vigorously phagocytic macrophage on the epithelial surface of lung alveoli that ingests carbon and other inhaled particulate matter. Also called coniophage or dust cell.

Alzheimer's disease A degenerative, organic, mental disease characterised by progressive brain deterioration and dementia usually occurring after the age of 50.

Amastigote Refers to a cell that does not have any flagella, used mainly to describe a certain phase in the life cycle of trypanosome protozoans.

Amenorrhea The condition when a woman fails to have menstrual periods.

Amidolytic Cleavage of the amide structure.

Amoebiasis State of being infected by amoeba such as *Entamoeba histolytica*.

Amoebicidal Lethal to amoeba.

AMPK (5′ AMP-activated protein kinase) Or 5′ adenosine monophosphate-activated protein kinase, enzyme that plays a role in cellular energy homeostasis.

Amygdalitis Inflammation of one or both tonsils, tonsilitis.

Amyloid beta (Aβ or Abeta) A peptide of 39–43 amino acids that appears to be the main constituent of amyloid plaques in the brains of Alzheimer's disease patients.

Amyloidosis A disorder that results from abnormal deposition of the protein amyloid in various tissues of the body.

Amyotrophic lateral sclerosis Or ALS, is a disease of the motor neurons in the brain and spinal cord that control voluntary muscle movement.

Amyotrophy Progressive wasting of muscle tissues. *adj*. amyotrophic.

Anaemia A blood disorder in which the blood is deficient in red blood cells and in haemoglobin.

Anaesthesia Condition of having sensation temporarily suppressed.

Anaesthetic A substance that partially or totally decreases the nerve sense of pain.

Analeptic A central nervous system (CNS) stimulant medication.

Analgesia Term describing relief, reduction or suppression of pain. *adj*. analgetic.

Analgesic A substance that relieves or reduces pain.

Anaphoretic An antiperspirant.

Anaphodisiac Or antiaphrodisiac, is something that reduces or blunts the libido.

Anaphylaxis A severe, life-threatening allergic response that may be characterised by symptoms such as reduced blood pressure, wheezing, vomiting or diarrhoea.

Anaphylactic *Adj*. See anaphylaxis.

Anaphylotoxins Are fragments (C3a, C4a or C5a) that are produced during the pathways of the complement system. They can trigger release of substances of endothelial cells, mast cells or phagocytes, which produce a local inflammatory response.

Anaplasia A reversion of differentiation in cells, is characteristic of malignant neoplasms (tumours).

Anaplastic *Adj*. See anaplasia.

Anasarca Accumulation of a great quantity of fluid in body tissues.

Anencephaly A cephalic disorder that results from a neural tube defect that occurs when the cephalic (head) end of the neural tube fails to close, resulting in the absence of a major portion of the brain, skull and scalp.

Androgen Male sex hormone in vertebrates. Androgens may be used in patients with breast cancer to treat recurrence of the disease.

Androgenic alopecia Hair loss in men and women.

Android adiposity Centric fat distribution patterns with increased disposition towards the abdominal area, visceral fat – apple-shaped *cf*. gynoid adiposity.

Andrology Branch of medicine concerned with reproductive diseases in men.

Aneugen An agent that affects cell division and the mitotic spindle apparatus, causing the loss or gain of whole chromosomes, thereby inducing aneuploidy. *adj*. aneugenic.

Angina pectoris, Angina Chest pain or chest discomfort that occurs when the heart muscle does not get enough blood.

Angioedema Rapid swelling of the dermis, subcutaneous tissues, mucosa and submucosal tissues caused by small blood vessels leaking fluid into these tissues.

Angiogenic *Adj*. See angiogenesis.

Angiogenesis A physiological process involving the growth of new blood vessels from pre-existing vessels.

Angiotensin An oligopeptide hormone in the blood that causes blood vessels to constrict and drives blood pressure up. It is part of the renin–angiotensin system.

Angiotensin-converting enzyme (ACE) An exopeptidase, a circulating enzyme that participates in the body's renin–angiotensin system (RAS), which mediates extracellular volume (i.e. that of the blood plasma, lymph and interstitial fluid) and arterial vasoconstriction.

Angioplasty Medical procedure used to open obstructed or narrowed blood vessels resulting usually from atherosclerosis.

Anguillulosis A parasitosis caused by the intestinal nematode *Strongyloides stercoralis* (round worm).

Anisakiasis A human parasitic infection of the gastrointestinal tract caused by the consumption of raw or undercooked seafood containing larvae of the nematode *Anisakis simplex.*

Anisonucleosis A morphological manifestation of nuclear injury characterised by variation in the size of cell nuclei.

Ankylosing spondylitis (AS) Is a type of inflammatory arthritis that targets the joints of the spine.

Annexin V Or Annexin A5, is a member of the annexin family of intracellular proteins that binds to phosphatidylserine (PS) in a calcium-dependent manner.

Annexitis Also called adnexitis, a pelvic inflammatory disease involving the inflammation of the ovaries or fallopian tubes.

Anodyne A substance that relieves or soothes pain by lessening the sensitivity of the brain or nervous system. Also called an analgesic.

Anoikis Apoptosis that is induced by inadequate or inappropriate cell–matrix interactions.

Anorectal Relating to the rectum and anus.

Anorectics Appetite suppressants, substances which reduce the desire to eat. Used on a short-term basis clinically to treat obesity. Also called anorexigenics.

Anorexia Lack or loss of desire to eat.

Anorexic Having no appetite to eat.

Anorexigenics See anorectics.

Anosmia Inabity to perceive odour, reduced sense of smell.

Anoxia Absence of oxygen supply.

Antagonist A substance that acts against and blocks an action.

Antalgic A substance used to relieve a painful condition.

Antecubital vein This vein is located in the antecubital fossa —the area of the arm in front of the elbow.

Anterior uveitis Is the most common form of ocular inflammation that often causes a painful red eye.

Anthelmintic An agent or substance that is destructive to worms and used for expulsion of internal parasitic worms in animals and humans.

Anthocyanins A subgroup of antioxidant flavonoids, they are glucosides of anthocyanidins, which are beneficial to health. They occur as water-soluble vacuolar pigments that may appear red, purple or blue according to pH in plants.

Anthrax A bacterial disease of cattle and sheep that can be transmitted to man through unprocessed wool.

Anthropometric Pertaining to the study of human body measurements.

Antiamoebic A substance that destroys or suppresses parasitic amoebae.

Antiamyloidogenic Compounds that inhibit the formation of Alzheimer's β-amyloid fibrils (fAβ) from amyloid β-peptide (Aβ) and destabilise fAβ.

Antianaphylactic Agent that can prevent the occurrence of anaphylaxis (life-threatening allergic response).

Antiangiogenic A drug or substance used to stop the growth of tumours and progression of cancers by limiting the pathological formation of new blood vessels (angiogenesis).

Antiarrhythmic A substance to correct irregular heartbeats and restore the normal rhythm.

Antiasthmatic Drug that treats or ameliorates asthma.

Antiatherogenic That protects against atherogenesis, the formation of atheromas (plaques) in arteries.

Antibacterial Substance that kills or inhibits bacteria.

Antibilious An agent or substance which helps remove excess bile from the body.

Antibiotic A chemical substance produced by a microorganism which has the capacity to inhibit the growth of or to kill other microorganisms.

Antiblennorrhagic A substance that treats blenorrhagia, a conjunctival inflammation resulting in mucous discharge.

Antibody A gamma globulin protein produced by a kind of white blood cell called the plasma cell in the blood used by the immune system to identify and neutralise foreign objects (antigen).

Anticarcinomic A substance that kills or inhibits carcinomas (any cancer that arises in epithelium/tissue cells).

Anticephalalgic Headache-relieving or preventing.

Anticestodal A chemical destructive to tapeworms.

Anticholesterolemic A substance that can prevent the build-up of cholesterol.

Anticlastogenic Having a suppressing effect of chromosomal aberrations.

Anticoagulant A substance that thins the blood and acts to inhibit blood platelets from sticking together.

Antidepressant A substance that suppresses depression or sadness.

Antidiabetic A substance that prevents or alleviates diabetes. Also called antidiabetogenic.

Antidiarrhoeal Having the property of stopping or correcting diarrhoea, an agent having such action.

Antidote A remedy for counteracting a poison.

Antidopaminergic A term for a chemical that prevents or counteracts the effects of dopamine.

Antidrepanocytary Anti-sickle cell anaemia.

Antidysenteric An agent used to reduce or treat dysentery and diarrhoea.

Antidyslipidemic Agent that will reduce the abnormal amount of lipids and lipoproteins in the blood.

Anti-oedematous Reduces or suppresses oedema.

Antiemetic An agent that stops vomiting and nausea.

Anti-epileptic A drug used to treat or prevent convulsions, anticonvulsant.

Antifebrile A substance that reduces fever, also called antipyretic.

Antifeedant Preventing something from being eaten.

Antifertility Agent that inhibits formation of ova and sperm and disrupts the process of fertilisation (antizygotic).

Antifibrosis Preventing/retarding the development of fibrosis i.e. excessive growth and activity of fibroblasts.

Antifilarial Effective against human filarial worms.

Antifungal An agent that kills or inhibits the growth of fungi.

Antigen A substance that prompts the production of antibodies and can cause an immune response. *adj*. antigenic.

Antigenotoxic An agent that inhibits DNA adduct formation, stimulates DNA repair mechanisms and possesses antioxidant functions.

Antiganacratia Antimenstruation.

Antigastralgic Preventing or alleviating gastric colic.

Antihematic Agent that stops vomiting.

Antihemorrhagic An agent which stops or prevents bleeding.

Antihepatotoxic Counteracting injuries to the liver.

Antiherpetic Having activity against herpes simplex virus (HSV).

Antihistamine An agent used to counteract the effects of histamine production in allergic reactions.

Antihyperalgesia The ability to block enhanced sensitivity to pain usually produced by nerve injury or inflammation or to nociceptive stimuli. *adj*. antihyperalgesic.

Antihypercholesterolemia Term to describe lowering of cholesterol level in the blood or blood serum.

Antihypercholesterolemic Agent that lowers chlolesterol level in the blood or blood serum.

Antihyperlidemic Promoting a reduction of lipid levels in the blood or an agent that has this action.

Antihypersensitive A substance used to treat excessive reactivity to any stimuli.

Antihypertensive A drug used in medicine and pharmacology to treat hypertension (high blood pressure).

Anti-inflammatory A substance used to reduce or prevent inflammation.

Antileishmanial Inhibiting the growth and proliferation of *Leishmania*, a genus of flagellate protozoans that are parasitic in the tissues of vertebrates.

Antileprotic Therapeutically effective against leprosy.

Antilithiatic An agent that reduces or suppresses urinary calculi (stones) and acts to dissolve those already present.

Antileukaemic Anticancer drugs that are used to treat leukaemia.

Antilithogenic Inhibiting the formation of calculi (stones).

Antimalarial An agent used to treat malaria and/or kill the malaria-causing organism, *Plasmodium* spp.

Antimelanogenesis Obstruction of production of melanin.

Antimicrobial A substance that destroys or inhibits growth of disease-causing bacteria, viruses, fungi and other microorganisms.

Antimitotic Inhibiting or preventing mitosis.

Antimutagenic An agent that inhibits mutations.

Antimycotic Antifungal.

Antineoplastic Said of a drug intended to inhibit or prevent the maturation and proliferation of neoplasms that may become malignant by targeting the DNA.

Antineuralgic A substance that stops intense intermittent pain, usually of the head or face, caused by neuralgia.

Antinociception Reduction in pain: a reduction in pain sensitivity produced within neurons when an endorphin or similar opium-containing substance (opioid) combines with a receptor.

Antinociceptive Having an analgesic effect.

Antioxytocic Inhibiting premature labour,. *cf.* tocolytic.

Antinutrient Are natural or synthetic compounds that interfere with the absorption of nutrients and are commonly found in food sources and beverages.

Antioestrogen A substance that inhibits the biological effects of female sex hormones.

Antiophidian Antivenom.

Antiosteoporotic Substance that can prevent osteoporosis.

Antiovulatory Substance suppressing ovulation.

Antioxidant A chemical compound or substance that inhibits oxidation and protects against free radical activity and lipid oxidation such as vitamin E, vitamin C or beta-carotene (converted to vitamin B), carotenoids and flavonoids which are thought to protect body cells from the damaging effects of oxidation. Many foods including fruit and vegetables contain compounds with antioxidant properties. Antioxidants may also reduce the risks of cancer and age-related macular degeneration (AMD).

Antipaludic Antimalarial.

Antiperiodic Substance that prevents the recurrence of symptoms of a disease e.g. malaria.

Antiperspirant A substance that inhibits sweating. Also called antisudorific, anaphoretic.

Antiphlogistic A traditional term for a substance used against inflammation, anti-inflammatory.

Antiplatelet agent Drug that decreases platelet aggregation and inhibits thrombus formation.

Antiplasmodial Suppressing or destroying plasmodia.

Antiproliferative Preventing or inhibiting the reproduction of similar cells.

Antiprostatic Drug to treat the prostate.

Antiprotozoal Suppressing the growth or reproduction of protozoa.

Antipruritic Alleviating or preventing itching.

Antipyretic A substance that reduces fever or quells it. Also known as antithermic.

Antirheumatic Relieving or preventing rheumatism.

Antiscorbutic A substance or plant rich in vitamin C that is used to counteract scurvy.

Antisecretory Inhibiting or diminishing secretion.

Antisense Refers to an antisense RNA strand because its sequence of nucleotides is the complement of message sense. When mRNA forms a duplex with a complementary antisense RNA sequence, translation of the mRNA into the protein is blocked. This may slow or halt the growth of cancer cells.

Antiseptic Preventing decay or putrefaction, a substance inhibiting the growth and development of microorganisms.

Antisickling agent An agent used to prevent or reverse the pathological events leading to sickling of erythrocytes in sickle-cell conditions.

Antispasmodic A substance that relieves spasms or inhibits the contraction of smooth muscles, smooth muscle relaxant, muscle relaxer.

Antispermatogenic Preventing or suppressing the production of semen or spermatozoa.

Antisudorific See antiperspirant.

Antisyphilitic A drug (or other chemical agent) that is effective against syphilis.

Antithermic A substance that reduces fever and temperature. Also known as antipyretic.

Antithrombotic Preventing or interfering with the formation of thrombi.

Antitoxin An antibody with the ability to neutralise a specific toxin.

Antitumoral Substance that acts against the growth, development or spread of a tumour.

Antitussive A substance that depresses coughing.

Antiulcerogenic An agent used to protect against the formation of ulcers or used for the treatment of ulcers.

Antivenin An agent used against the venom of a snake, spider or other venomous animal or insect.

Antivinous An agent or substance that treats addiction to alcohol.

Antiviral Substance that destroys or inhibits the growth and viability of infectious viruses.

Antivomitive A substance that reduces or suppresses vomiting.

Antizygotic See antifertility.

Anuria Absence of urine production and excretion. *adj*. anuric.

Anxiogenic Substance that causes anxiety.

Anxiolytic A drug prescribed for the treatment of symptoms of anxiety.

APAF-1 Apoptotic protease activating factor 1.

Apelin Also known as APLN, a peptide which in humans is encoded by the APLN gene.

Aperient A substance that acts as a mild laxative by increasing fluids in the bowel.

Aperitif An appetite stimulant.

Aphonia Loss of the voice resulting from disease, injury to the vocal cords or various psychological causes such as hysteria.

Aphrodisiac An agent that increases sexual activity and libido and/or improves sexual performance.

Aphthae White, painful oral ulcer of unknown cause.

Aphthous ulcer Also known as a canker sore, it is a type of oral ulcer which presents as a painful open sore inside the mouth or upper throat.

Aphthous stomatitis A canker sore, a type of painful oral ulcer or sore inside the mouth or upper throat, caused by a break in the mucous membrane. Also called aphthous ulcer.

Apnoea Suspension of external breathing.

Apoprotein The protein moiety of a molecule or complex, as of a lipoprotein.

Apolipoprotein A-I (APOA1) A major protein component of high-density lipoprotein (HDL) in plasma. The protein promotes cholesterol efflux from tissues to the liver for excretion.

Apolipoprotein B (APOB) Is the primary apolipoprotein of low-density lipoproteins (LDL or 'bad cholesterol'), which is responsible for carrying cholesterol to tissues.

Apolipoprotein E (APOE) The apolipoprotein found on intemediate-density lipoprotein and chylomicron that binds to a specific receptor on liver and peripheral cells.

Apoplexy Unconsciousness or incapacity of the brain to function, resulting from a cerebral haemorrhage or stroke.

Apoptogenic Ability to cause death of cells.

Apoptosis Death of cells.

Appendicitis Is a condition characterised by inflammation of the appendix. Also called epityphlitis.

Appetite stimulant A substance to increase or stimulate the appetite. Also called aperitif.

aPTT (Activated Partial Thromboplastin Time) A blood test, a measure of the part of the blood-clotting pathway.

Apurinic lyase A DNA enzyme that catalyses a chemical reaction.

Arachidonate cascade Includes the cyclooxygenase (COX) pathway to form prostanoids and the lipoxygenase (LOX) pathway to generate several oxygenated fatty acids collectively called eicosanoids.

ARE Antioxidant response element, is a transcriptional control element that mediates expression of a set of antioxidant proteins.

Aribоflavinosis A condition caused by the dietary deficiency of riboflavin that is characterised by mouth lesions, seborrhea and vascularisation.

Aromatase An enzyme involved in the production of oestrogen that acts by catalysing the conversion of testosterone (an androgen) to estradiol (an oestrogen). Aromatase is located in oestrogen-producing cells in the adrenal glands, ovaries, placenta, testicles, adipose (fat) tissue and brain.

Aromatic Having a pleasant fragrant odour.

Aromatherapy A form of alternative medicine that uses volatile liquid plant materials such as essential oils and other scented compounds from plants for the purpose of affecting a person's mood or health.

ARPE-19 cells A human retinal pigment epithelial cell line with differentiated properties.

Arrhythmias Abnormal heart rhythms that can cause the heart to pump less effectively. Also called dysrhythmias.

Arsenicosis See arsenism.

Arsenism An incommunicable disease resulting from the ingestion of groundwater containing unsafe levels of arsenic, also known as arsenicosis.

Arteriogenic erectile dysfunction A penis dysfunction caused by the narrowing of the arteries in the penis decreasing blood inflow to it, thus making erection impossible.

Arteriosclerosis Imprecise term for various disorders of arteries, particularly hardening due to fibrosis or calcium deposition, often used as a synonym for atherosclerosis.

Arthralgia Is pain in the joints from many possible causes.

Arthritis Inflammation of the joints of the body.

Arthrodynia An affection characterised by pain in or about a joint.

Arthus reaction An allergic reaction of the immediate hypersensitive type that results from the union of antigen and antibody, with complement present, in blood vessel walls.

Aryl hydrocarbon receptor (AhR) A ligand-activated transcription factor best known for mediating the toxicity of dioxin and other exogenous contaminants and responsible for their toxic effects including immunosuppression.

ASATor AST Aspartate aminotransferase, see aspartate transaminase.

ASBT Apical sodium-dependent bile acid transporter belongs to the solute carrier family (SLC) of transporters and is an important carrier protein expressed in the small intestine.

Ascaris A genus of parasitic intestinal roundworms.

Ascites Abnormal accumulation of fluid within the abdominal or peritoneal cavity.

Ascorbic acid See vitamin C.

Aspartate transaminase (AST) Also called Serum Glutamic Oxaloacetic Transaminase (SGOT) or aspartate aminotransferase (ASAT), it is similar to ALT in that it is another enzyme associated with liver parenchymal cells. It is increased in acute liver damage but is also present in red blood cells and cardiac and skeletal muscle and is therefore not specific to the liver.

Asphyxia Failure or suppression of the respiratory process due to obstruction of airflow to the lungs or to the lack of oxygen in inspired air.

Asphyxiation The process of undergoing asphyxia.

Asthenia A nonspecific symptom characterised by loss of energy and strength and feeling of weakness.

Asthenopia Weakness or fatigue of the eyes usually accompanied by headache and dimming of vision. *adj*. asthenopic.

Asthma A chronic illness involving the respiratory system in which the airway occasionally constricts, becomes inflamed and is lined with excessive amounts of mucus often in response to one or more triggers.

Astringent A substance that contracts blood vessels and certain body tissues (such as mucous membranes) with the effect of reducing secretion and excretion of fluids and/or has a drying effect.

Astrocytes Collectively called astroglia, they are characteristic star-shaped glial cells in the brain and spinal cord.

Ataxia (Loss of coordination) results from the degeneration of nerve tissue in the spinal cord

and of nerves that control muscle movement in the arms and legs.

Ataxia telangiectasia and Rad3-related protein (ATR) Also known as Serine/threonine-protein kinase ATR, FRAP-related protein 1 (FRP1) is an enzyme encoded by the ATR gene. It is involved in sensing DNA damage and activating the DNA damage checkpoint leading to cell cycle arrest.

Atelectasis The collapse or closure of the lung resulting in reduced or absent gas exchange.

ATF-2 Activating transcription factor 2.

Athlete's foot A contagious skin disease caused by parasitic fungi affecting the foot and hands, causing itching, blisters and cracking. Also called dermatophytosis.

Atherogenic Having the capacity to start or accelerate the process of atherogenesis.

Atherogenesis The formation of lipid deposits in arteries.

Atheroma A deposit or degenerative accumulation of lipid-containing plaques on the innermost layer of the wall of an artery.

Atherosclerosis The condition in which an artery wall thickens as the result of a build-up of fatty materials such as cholesterol.

Atherothrombosis Medical condition characterised by an unpredictable, sudden disruption (rupture or erosion/fissure) of an atherosclerotic plaque, which leads to platelet activation and thrombus formation.

Athymic mice Laboratory mice lacking a thymus gland.

Atonic Lacking normal tone or strength.

Atony Insufficient muscular tone.

Atopic dermatitis An inflammatory, non-contagious, pruritic skin disorder of unknown aetiology, often called eczema.

Atresia A congenital medical condition in which a body orifice or passage in the body is abnormally closed or absent.

Atretic follicle Follicular atresia is the breakdown of ovarian follicles.

Atretic ovarian follicle An involuted or closed ovarian follicle.

Atrial fibrillation Is the most common cardiac arrhythmia (abnormal heart rhythm) and involves the two upper chambers (atria) of the heart; the most serious consequence of atrial fribillation is ischaemic stroke.

Atrioventricular node A node of specialised heart muscle located in the septal wall of the right atrium receives impulses from the sino-atrial node and directs them to the walls of the ventricles.

Attention deficit hyperactivity disorder (ADHD, ADD or AD/HD) Is a neurobehavioural developmental disorder primarily characterised by the co-existence of attentional problems and hyperactivity.

Auditory brainstem response (ABR) Also called brainstem evoked response (BSER), it is an electrical signal evoked from the brainstem of a human by the presentation of a sound such as a click.

Augmerosen A drug that may kill cancer cells by blocking the production of a protein that makes cancer cells live longer. Also called bcl-2 antisense oligonucleotide.

Auricular Of or relating to the auricle or the ear in general.

Aurones [2-benzylidenebenzofuran-3(2H)-ones] are the secondary plant metabolites and are a subgroup of flavonoids. See flavonoids.

Autoantibodies Antibodies manufactured by the immune system that mistakenly target and damage specific tissues and organs of the body.

Autolysin An enzyme that hydrolyses and destroys the components of a biological cell or a tissue in which it is produced.

Autonomic disorder A neurological disease in which the autonomic nervous system ceases to function properly.

Autophagy Digestion of cell contents by enzymes in the same cell.

Autopsy Examination of a cadaver to determine or confirm the cause of death.

Avenanthramides Low–molecular weight, soluble phenolic compounds found in oats.

Avidity index Describes the collective interactions between antibodies and a multivalent antigen.

Avulsed tooth Is a tooth that has been knocked out.

Ayurvedic Traditional Hindu system of medicine based largely on homeopathy and naturopathy.

Azoospermia Is the medical condition of a male not having any measurable level of sperm in his semen.

Azotaemia A higher-than-normal blood level of urea or other nitrogen-containing compounds in the blood.

B-cell activating factor (BAFF) Also called tumor necrosis factor ligand superfamily member 13B. It plays an important role in the proliferation and differentiation of B cells.

Babesia A protozoan parasite (malaria-like) of the blood that causes a hemolytic disease known as Babesiosis.

Babesiosis Malaria-like parasitic disease caused by Babesia, a genus of protozoal piroplasms.

Back tonus Normal state of balanced tension in the tissues of the back.

Bactericidal Lethal to bacteria.

BAFF A cytokine that belongs to the tumor necrosis factor (TNF) ligand family.

Balanitis Is an inflammation of the glans (head) of the penis.

BALB/c mice The balb/c mouse was developed in 1923 by McDowell. It is a popular strain and is used in many different research disciplines but most often in the production of monoclonal antibodies.

Balm Aromatic oily resin from certain trees and shrubs used in medicine.

Baroreceptor A type of interoceptor that is stimulated by pressure changes, as those in blood vessel walls.

Barrett's oesophagus (Barrett oesophagitis) A disorder in which the lining of the oesophagus is damaged by stomach acid.

Basophil A type of white blood cell with coarse granules within the cytoplasm and a bilobate (two-lobed) nucleus.

Bax/Bad Proapoptotic proteins.

BCL-2 A family of apoptosis regulatory proteins in humans encoded by the B-cell lymphoma 2 (BCL-2) gene.

BCL-2 antisense oligonucleotide See augmereson.

BCR/ABL A chimeric oncogene from a fusion of BCR and ABL cancer genes associated with chronic myelogenous leukaemia.

Bechic A remedy or treatment of cough.

Bed nucleus of the stria terminalis (BNST) Acts as a relay site within the hypothalamic–pituitary–adrenal axis and regulates its activity in response to acute stress.

Belching, or burping Refers to the noisy release of air or gas from the stomach through the mouth.

Beriberi Is a disease caused by a deficiency of thiamine (vitamin B1) that affects many systems of the body including the muscles, heart, nerves and digestive system.

Beta-carotene Naturally occurring retinol (vitamin A) precursor obtained from certain fruit and vegetables with potential antineoplastic and chemopreventive activities. As an antioxidant, beta-carotene inhibits free-radical damage to DNA. This agent also induces cell differentiation and apoptosis of some tumour cell types, particularly in early stages of tumorigenesis, and enhances immune system activity by stimulating the release of natural killer cells, lymphocytes, and monocytes.

Beta-catenin Is a multifunctional oncogenic protein that contributes fundamentally to cell development and biology; it has been implicated as an integral component in the Wnt signaling pathway.

Beta cells A type of cell in the pancreas in areas called the islets of Langerhans.

Beta glucans Polysaccharides of D-glucose monomers linked by β-glycosidic bonds, (1→3), (1→4)-β-D-glucan, soluble, viscous component of fibres found in cereals like oats.

Beta-thalassemia An inherited blood disorder that reduces the production of haemoglobin.

Beta-lactamases Enzymes produced by some bacteria that are responsible for their resistance to beta-lactam antibiotics like penicillins.

BHT Butylated hydroxytoluene (phenolic compound), an antioxidant used in foods, cosmetics, pharmaceuticals and petroleum products.

BID The only known Bcl-2 family member that can function as an agonist of proapoptotic Bcl-2-related proteins such as Bax and Bak.

Bifidobacterium Is a genus of gram-positive, non-motile, often branched anaerobic bacteria. Bifidobacteria are one of the major genera of bacteria that make up the gut flora. Bifidobacteria aid in digestion, are associated with a lower incidence of allergies and also prevent some forms of tumour growth. Some bifidobacteria are being used as probiotics.

Bifidogenic Promoting the growth of (beneficial) bifidobacteria in the intestinal tract.

Bile Fluid secreted by the liver and discharged into the duodenum, where it is integral in the digestion and absorption of fats.

Bilharzia, bilharziosis See Schistosomiasis.

Biliary Relating to the bile or the organs in which the bile is contained or transported.

Biliary infections Infection of organ(s) associated with bile, comprising (a) acute cholecystitis: an acute inflammation of the gallbladder wall; (b) cholangitis: inflammation of bile ducts.

Biliousness Old term used in the eighteenth and nineteenth centuries pertaining to bad digestion, stomach pains, constipation and excessive flatulence.

Bilirubin A breakdown product of heme (a part of haemoglobin in red blood cells) produced by the liver that is excreted in bile, which causes a yellow discoloration of the skin and eyes when it accumulates in those organs.

Biotin Also known as vitamin B7. See vitamin B7.

Bitter A medicinal agent with a bitter taste used as a tonic, alterative or appetiser.

Blackhead See comedone.

Blackwater fever Dangerous complication of malaria whereby red blood cells burst in the bloodstream (haemolysis), releasing haemoglobin directly into the blood.

Blain See chilblain.

Blastocyst Blastocyst is an embryonic structure formed in the early embryogenesis of mammals after the formation of the morula but before implantation.

Blastocystotoxic Agent that suppresses further development of the blastocyst through to the ovum stage.

Blebbing Bulging, e.g. membrane blebbing, also called membrane bulging or ballooning.

Bleeding diathesis Is an unusual susceptibility to bleeding (haemorrhage) due to a defect in the system of coagulation.

Blennorrhagia Gonorrhea.

Blennorrhea Inordinate discharge of mucus, especially a gonorrheal discharge from the urethra or vagina.

Blepharitis Inflammation of eyelids.

Blepharospasm Involuntary twitching, blinking closure or squeezing of eyelids.

Blister Thin vesicle on the skin containing serum and caused by rubbing, friction or burn.

Blood–brain barrier (BBB) Is a separation of circulating blood and cerebrospinal fluid (CSF) in the central nervous system (CNS). It allows essential metabolites such as oxygen and glucose to pass from the blood to the brain and central nervous system (CNS) but blocks most molecules that are more massive than about 500 Da.

Blood stasis syndrome Blood stagnation or slowing of blood, an important underlying pathology of many disease processes according to traditional Chinese medicine.

BMPs (bone morphogenetic proteins) A family of secreted signaling molecules that can induce ectopic bone growth.

BNIP3 A pro-apoptotic BH3-only protein which is associated with mitochondrial dysfunction and cell death.

Boil Localised pyrogenic, painful infection originating in a hair follicle.

Borborygmus Rumbling noise caused by the muscular contractions of peristalsis, the process that moves the contents of the stomach and intestines downwards.

Bowman Birk inhibitors Type of serine proteinase inhibitor.

Bouillon A broth in French cuisine.

Bradicardia As applied to adult medicine, it is defined as a resting heart rate of under 60 beats per minute.

Bradyphrenia Referring to the slowness of thought common to many disorders of the brain.

Brain-derived neutrophic factor (BDNF) A protein member of the neutrophin family that plays an important role in the growth, maintenance, function and survival of neurons. The protein molecule is involved in the modulation of cognitive and emotional functions and in the treatment of a variety of mental disorders.

Bright's disease Chronic nephritis.

Bronchial inflammation See bronchitis.

Bronchiectasis A condition in which the airways within the lungs (bronchial tubes) become damaged and widened.

Bronchitis Is an inflammation of the main air passages (bronchi) to the lungs.

Bronchoalveolar lavage (BAL) A medical procedure in which a bronchoscope is passed through the mouth or nose into the lungs and fluid is squirted into a small part of the lung and then recollected for examination.

Bronchopneumonia Or bronchial pneumonia; inflammation of the lungs beginning in the terminal bronchioles.

Bronchopulmonary Relating to the bronchi and lungs.

Bronchospasm Is a difficulty in breathing caused by a sudden constriction of muscles in the walls of the bronchioles as occurs in asthma.

Brown fat Brown adipose tissue (BAT) in mammals; its primary function is to generate body heat in animals or newborns that do not shiver.

Bubo Inflamed, swollen lymph node in the neck or groin.

Buccal Of or relating to the cheeks or the mouth cavity.

Bulbectomy Removal of the olfactory bulb.

Bullae Blisters; circumscribed, fluid-containing, elevated lesions of the skin usually more than 5 mm in diameter.

Bursa A fluid-filled sac or saclike cavity situated in areas subject to friction.

Bursitis Condition characterised by inflammation of one or more bursae (small sacs) of synovial fluid in the body.

C fibres Afferent fibres found in the nerve of the somatic sensory system.

c-FOS A cellular proto-oncogene belonging to the immediate early gene family of transcription factors.

C-jun NH(2)-terminal kinase Enzymes that belong to the family of the MAPK superfamily of protein kinases. These kinases mediate a plethora of cellular responses to such stressful stimuli including apoptosis and production of inflammatory and immunoregulatory cytokines in diverse cell systems. *cf*: MAPK.

c-Jun-I (Ser 73) Substrate of JNK-1 activated by phosphorylation at Ser73.

c-Jun II (Ser 63) Substrate of JNK-1 activated by phosphorylation at Ser63.

C-reactive protein A protein found in the blood, the levels of which rise in response to inflammation.

c-Src A cellular non-receptor tyrosine kinase.

CAAT element-binding proteins-alpha (c/EBP-alpha) Regulates gene expression in adipocytes in the liver.

Cachexia Physical wasting with loss of weight, muscle atrophy, fatigue and weakness caused by disease.

Caco-2 cell line A continuous line of heterogeneous human epithelial colorectal adenocarcinoma cells.

Cadaver A dead body, corpse.

$Ca2^+$ ATPase (PMCA) is a transport protein in the plasma membrane of cells that serves to remove calcium ($Ca2^+$) from the cell.

Calcitonin gene-related peptide (CGRP) is a 37-amino acid neuropeptide that is abundant in the sensory neurons which innervate bone.

Calcium (Ca) Is the most abundant mineral in the body found mainly in bones and teeth. It is required for muscle contraction, blood vessel expansion and contraction, secretion of hormones and enzymes and transmitting impulses throughout the nervous system. Dietary sources include milk, yoghurt, cheese, Chinese cabbage, kale, broccoli, some green leafy vegetables, fortified cereals, beverages and soybean products.

Calcium ATPase Is a form of P-ATPase which transfers calcium after a muscle has contracted.

Calcium channel blockers (CCBs) A class of drugs and natural substances that disrupt the calcium (Ca2+) conduction of calcium channels.

Calciuria Abnormal presence of calcium in urine.

Calculosis The tendency or deposition to form calculi or stones.

Calculus (calculi) Hardened, mineral deposits that can form a blockage in the urinary system.

Calculi infection Most calculi arise in the kidney when urine becomes supersaturated with a salt that is capable of forming solid crystals. Symptoms arise as these calculi become impacted within the ureter as they pass towards the urinary bladder.

Caligo Dimness or obscurity of sight dependent upon a speck on the cornea.

Calmodulin Is a calcium-modulated protein that can bind to and regulate a multitude of

different protein targets, thereby affecting many different cellular functions.

cAMP-dependent pathway Cyclic adenosine monophosphate is a G protein-coupled receptor-triggered signaling cascade used in cell communication in living organisms.

CAMP factor Diffusible, heat-stable, extracellular protein produced by Group B *Streptococcus t*hat enhances the hemolysis of sheep erythrocytes by *Staphylococcus aureus*. It is named after Christie, Atkins and Munch-Peterson, who described it in 1944.

Campylobacteriosis Is a gastrointestinal disease (gastroenteritis) caused by bacteria called *Campylobacter* which is frequently associated with the consumption of contaminated poultry.

Cancer A malignant neoplasm or tumour in nay part of the body.

Candidiasis Infections caused by members of the fungus genus *Candida* that range from superficial such as oral thrush and vaginitis to systemic and potentially life-threatening diseases.

Canker See chancre.

Cannabinoid receptor family Includes CB1 cannabinoid receptors found predominantly in the brain and nervous sytem and CB2 cannabinoid receptors mainly associated with immune tissues and expressed at low levels in the brain.

Cannabinoid receptor type 2 (CB 2 receptor) A G protein-coupled receptor from the cannabinoid receptor family that is mainly expressed on T cells of the immune system, on macrophages and B cells and in hematopoietic cells.

Carboxypeptidase An enzyme that hydrolyses the carboxy-terminal (C-terminal) end of a peptide bond. It is synthesised in the pancreas and secreted into the small intestine.

Carbuncle Is an abscess larger than a boil, usually with one or more openings draining pus onto the skin.

Carcinogenesis Production of carcinomas. *adj*. carcinogenic.

Carcinoma Any malignant cancer that arises from epithelial cells.

Carcinosarcoma A rare tumour containing carcinomatous and sarcomatous components.

Cardiac Relating to, situated near or affecting the heart.

Cardiac asthma Acute attack of dyspnoea with wheezing resulting from a cardiac disorder.

Cardiac hypertrophy Is a thickening of the heart muscle (myocardium) resulting in a decreased chamber size including the left and right ventricles. Common causes of cardiac hypertrophy include high blood pressure (hypertension) and heart valve stenosis.

Cardialgia Heartburn.

Cardinolides Cardiac glycosides with a five-membered lactone ring in the side chain of the steroid aglycone.

Cardinolide glycoside Cardenolides that contain structural groups derived from sugars.

Cardioactive Having an effect on the heart.

Cardiogenic shock Is characterised by a decreased pumping ability of the heart that causes a shock-like state associated with an inadequate circulation of blood due to primary failure of the ventricles of the heart to function effectively.

Cardiomyocytes Cardiac muscle cells.

Cardiomyopathy Heart muscle disease.

Cardiopathy Disease or disorder of the heart.

Cardioplegia Stopping the heart so that surgical procedures can proceed in a still and bloodless field.

Cardiotonic Something which strengthens, tones or regulates heart functions without overt stimulation or depression.

Cardiovascular Pertaining to the heart and blood vessels.

Caries Tooth decay, commonly called cavities.

Cariogenic Leading to the production of caries.

Carminative Substance that stops the formation of intestinal gas and helps expel gas that has already formed, relieving flatulence: relieving flatulence or colic by expelling gas.

Carnitine palmitoyltransferase I (CPT1) Also known as carnitine acyltransferase I or CAT1, it is a mitochondrial enzyme involved in converting long-chain fatty acid into energy.

Carotenes Are a large group of intense red and yellow pigments found in all plants; these are hydrocarbon carotenoids (subclass of tetraterpenes), and the principal carotene is beta-carotene, which is a precursor of vitamin A.

Carotenoids A class of natural fat-soluble pigments found principally in plants, belonging to a subgroup of terpenoids containing eight isoprene units forming a C40 polyene chain.

Carotenoids play an important potential role in human health by acting as biological antioxidants. See also carotenes.

Carotenodermia Yellow skin discoloration caused by excess blood carotene.

Carpopedal spasm Spasm of the hand or foot or of the thumbs and great toes.

Capases Cysteine-aspartic acid proteases are a family of cysteine proteases which play essential roles in apoptosis (programmed cell death), necrosis and inflammation.

Catalase (CAT) Enzyme in living organism that catalyses the decomposition of hydrogen peroxide to water and oxygen.

Catalepsy Indefinitely prolonged maintenance of a fixed body posture seen in severe cases of catatonic schizophrenia.

Catamenia Menstruation.

Cataplasia Degenerative reversion of cells or tissue to a less differentiated form.

Cataplasm A medicated poultice or plaster. A soft moist mass, often warm and medicated, that is spread over the skin to treat an inflamed, aching or painful area to improve circulation.

Cataractogenesis Formation of cataracts.

Catarrh, Catarrhal Inflammation of mucous membranes especially of the nose and throat.

Catechins Are polyphenolic antioxidant plant metabolites. They belong to the family of flavonoids; tea is a rich source of catechins. See flavonoids.

Catecholamines Hormones that are released by adrenal glands in response to stress.

Cathartic Is a substance which accelerates defecation.

Caustic Having a corrosive or burning effect.

Cauterisation A medical term describing the burning of the body to remove or close a part of it.

Caveolae Tiny (50–100 nm) invaginations of the plasma membrane of the cell.

CB-1 receptor Cannabinoid receptor type 1 held to be one of the most widely expressed G protein-coupled receptors in the brain.

CCAAT/enhancer-binding proteins (C/EBP) Family of transcription factors that interact with CCAAT (cytidine-cytidine-adenosine-adenosine-thymidine) box motif.

CCAAT/enhancer-binding protein (C/EBP) α A key adipogenic transcription factor.

cdc2 Kinase A member of cyclin-dependent protein kinases (CDKs).

CDKs Cyclin-dependent protein kinases, a family of serine/threonine kinases that mediate many stages in mitosis.

CD4T cell Helper T cell with CD4 receptor that recognises antigens on the surface of a virus-infected cell and secretes lymphokines that stimulate B cells and killer T cells.

CD 28 Is one of the molecules expressed on T cells that provide co-stimulatory signals, which are required for T-cell (lymphocytes) activation.

CD31 Also known as PECAM-1 (platelet endothelial cell adhesion molecule-1), a member of the immunoglobulin superfamily that mediates cell-to-cell adhesion.

CD36 An integral membrane protein found on the surface of many cell types in vertebrate animals.

CD40 An integral membrane protein found on the surface of B lymphocytes, dendritic cells, follicular dendritic cells, hematopoietic progenitor cells, epithelial cells and carcinomas.

CD68 A glycoprotein expressed on monocytes/macrophages which binds to low-density lipoprotein.

Cecal ligation Tying up the cecam.

Celiac disease An autoimmune disorder of the small intestine triggered in genetically susceptible individuals by ingested gluten from wheat, rye, barley and other closely related cereal grains. Peptides resulting from partially digested gluten of wheat, barley or rye cause inflammation of the small intestinal mucosa.

Cell adhesion molecules (CAM) Glycoproteins located on the surface of cell membranes involved with binding of other cells or with the extra-cellular matrix.

Cellular respiration Is the set of the metabolic reactions and processes that take place in organisms' cells to convert biochemical energy from nutrients into adenosine triphosphate (ATP) and then release waste products. The reactions involved in respiration are catabolic reactions that involve the oxidation of one molecule and the reduction of another.

Cellulitis A bacterial infection of the skin that tends to occur in areas that have been damaged or inflamed.

Central nervous system Part of the vertebrate nervous system comprising the brain and spinal cord.

Central venous catheter A catheter placed into the large vein in the neck, chest or groin.

Cephalagia Pain in the head, a headache.

Cephalic Relating to the head.

Ceramide oligosides Oligosides with an N-acetyl-sphingosine moiety.

Cercariae A free-swimming larva of the parasitic schistosome worm that has a tail and suckers on its head for penetration into a host.

Cerebral embolism A blockage of blood flow through a vessel in the brain by a blood clot that formed elsewhere in the body and traveled to the brain.

Cerebral ischaemia Is the localised reduction of blood flow to the brain or parts of the brain due to arterial obstruction or systematic hyperfusion.

Cerebral infarction Is the ischaemic kind of stroke due to a disturbance in blood vessels supplying blood to the brain.

Cerebral tonic Substance that can alleviate poor concentration and memory, restlessness, uneasiness and insomnia.

Cerebrosides Are glycosphingolipids which are important components in animal muscle and nerve cell membranes.

Cerebrovascular disease Is a group of brain dysfunctions related to disease of blood vessels supplying the brain.

Cerumen Ear wax, a yellowish waxy substance secreted in the ear canal of humans and other mammals.

cFLIP Cellular FLICE-inhibitory protein, an inhibitor of death ligand-induced apoptosis.

cGMP Cyclic guanosine monophosphate is a cyclic nucleotide derived from guanosine triphosphate (GTP). cGMP is a common regulator of ion channel conductance, glycogenolysis and cellular apoptosis. It also relaxes smooth muscle tissues.

CGRP calcitonin gene-related peptide A vasodilator neuropeptide that is expressed in a subgroup of small neurons in the dorsal root, trigeminal and vagal ganglia. This neuropeptide has been postulated to play a role in the pathophysiology of migraine.

Chalcones A subgroup of flavonoids.

Chancre A painless lesion formed during the primary stage of syphilis.

Chaperones Are proteins that assist the non-covalent folding or unfolding and the assembly or disassembly of other macromolecular structures.

Chemoembolisation A procedure in which the blood supply to the tumour is blocked surgically or mechanically and anticancer drugs are administered directly into the tumour.

Chemokines Are chemotactic cytokines which stimulate migration of inflammatory cells towards tissue sites of inflammation.

Chemonociceptors Nociceptors or sensory peripheral neurons that are sensitive to chemical stimuli.

Chemosensitiser A drug that makes tumour cells more sensitive to the effects of chemotherapy.

Chemosis Oedema of the conjunctiva of the eye.

Chickenpox Is also known as varicella, a highly contagious illness caused by primary infection with varicella zoster virus (VZV). The virus causes red, itchy bumps on the body.

Chilblains Small, itchy, painful lumps that develop on the skin. They develop as an abnormal response to cold. Also called perniosis or blain.

Chlorosis Iron deficiency anaemia characterised by a greenish yellow colour.

Cholagogue Is a medicinal agent which promotes the discharge of bile from the system.

Cholecalcifereol A form of vitamin D also called vitamin D3. See vitamin D.

Cholecyst Gall bladder.

Cholecystitis Inflammation of the gall bladder.

Cholecystokinin A peptide hormone that plays a key role in facilitating digestion in the small intestine.

Cholera An infectious gastroenteritis caused by enterotoxin-producing strains of the bacterium *Vibrio cholera* and characterised by severe, watery diarrhoea.

Choleretic Stimulation of the production of bile by the liver.

Cholestasis A condition caused by rapidly developing (acute) or long-term (chronic) interruption in the excretion of bile from the liver to the duodenum.

Cholesterol A soft, waxy steroid substance found among lipids (fats) in the bloodstream and in all our body's cells.

Cholethiasis Presence of gall stones (calculi) in the gall bladder.

Choline A water-soluble organic compound usually grouped within the Vitamin B complex. It is an essential nutrient and is needed for physiological functions such as structural integrity and signaling roles for cell membranes and cholinergic neuro-transmission (acetylcholine synthesis).

Cholinergic Activated by or capable of liberating acetylcholine especially in the parasympathetic nervous system.

Cholinergic system A system of nerve cells that uses acetylcholine in transmitting nerve impulses.

Cholinomimetic Having an action similar to that of acetylcholine, also called parasympathomimetic.

Chonotropic Affecting the time or rate, as the rate of contraction of the heart.

Choriocarcinoma A quick-growing, malignant, trophoblastic, aggressive cancer that occurs in a woman's uterus (womb).

Chromium (Cr) Is required in trace amounts in humans for sugar and lipid metabolism. Its deficiency may cause a disease called chromium deficiency. It is found in cereals, legumes, nuts and animal sources.

Chromoblastomycosis A chronic fungal infection of the skin and subcutaneous tissue caused by traumatic inoculation of a specific group of dematiaceous fungi (such as *Fonsecaea pedrosoi, Phialophora verrucosa* and *Fonsecaea compacta*) through the skin.

Chromosome Long pieces of DNA found in the centre (nucleus) of cells.

Chronic Persisting over extended periods.

Chronic Obstructive Pulmonary Disease (COPD) A progressive disease that makes it hard to breathe.

Chronic venous insufficiency (CVI) A medical condition where the veins cannot pump enough oxygen-poor blood back to the heart.

Chronotropic Affecting the rate of rhythmic movements (e.g. heartbeat).

Chyle A milky bodily fluid consisting of lymph and emulsified fats or free fatty acids.

Chylomicrons Are large lipoprotein particles that transport dietary lipids from the intestines to other locations in the body. Chylomicrons are one of the five major groups of lipoproteins (chylomicrons, VLDL, IDL, LDL, HDL) that enable fats and cholesterol to move within the water-based solution of the bloodstream.

Chylorus Milky (having fat emulsion).

Chyluria Also called chylous urine, it is a medical condition involving the presence of chyle (emulsified fat) in the urine stream, which results in urine appearing milky.

Chymase Member of the family of serine proteases found primarily in mast cells.

Chymopapain An enzyme derived from papaya used in medicine and to tenderise meat.

Cicatrisant The term used to describe a product that promotes healing through the formation of scar tissue.

C-Kit receptor A protein-tyrosine kinase receptor that is specific for stem cell factor. This interaction is crucial for the development of hematopoietic, gonadal and pigment stem cells.

Cirrhosis Chronic liver disease characterised by replacement of liver tissue by fibrous scar tissue and regenerative nodules/lumps leading progressively to loss of liver function.

Clastogen Is an agent that can cause one of two types of structural changes, breaks in chromosomes that result in the gain, loss or rearrangements of chromosomal segments. *adj*. clastogenic.

Claudication Limping, impairment in walking.

Climacterium Refers to menopause and the bodily and mental changes associated with it.

Clonic seizures Consist of rhythmic jerking movements of arms and legs, sometimes on both sides of the body.

Clonus A series of involuntary muscular contractions and relaxations.

Clyster Enema.

C-myc Codes for a protein that binds to the DNA of other genes and is therefore a transcription factor.

CNS depressant Anything that depresses or slows the sympathetic impulses of the central nervous system (i.e. respiratory rate, heart rate).

Coagulopathy A defect in the body's mechanism for blood clotting, causing susceptibility to bleeding.

Cobalamin Vitamin B12. See vitamin B12.

Co-carcinogen A chemical that promotes the effects of a carcinogen in the production of cancer.

Cold An acute inflammation of the mucous membrane of the respiratory tract especially of the nose and throat caused by a virus and accompanied by sneezing and coughing.

Collagen Protein that is the major constituent of cartilage and other connective tissue; comprises the amino acids hydroxyproline, proline, glycine and hydroxylysine.

Collagenases Enzymes that break peptide bonds in collagen.

Colibacillosis Infection with *Escherichia coli*.

Colic A broad term which refers to episodes of uncontrollable, extended crying in a baby who is otherwise healthy and well fed.

Colitis Inflammatory bowel disease affecting the tissue that lines the gastrointestinal system.

Collyrium A lotion or liquid wash used as a cleanser for the eyes, particularly in diseases of the eye.

Colorectal Relating to the colon or rectum.

Coma A state of unconsciousness from which a patient cannot be aroused.

Comedone A blocked, open sebaceous gland where the secretions oxidise, turning black. Also called blackhead.

Comitogen Agent that is considered not to induce cell growth alone but to promote the effect of the mitogen.

Concoction A combination of crude ingredients that are prepared or cooked together.

Condyloma, condylomata acuminata Genital warts, venereal warts, anal wart or anogenital wart, a highly contagious sexually transmitted infection caused by epidermotropic human papillomavirus (HPV).

Conglutination Becoming stuck together.

Conjunctival hyperemia Enlarged blood vessels in the eyes.

Conjunctivitis Sore, red and sticky eyes caused by eye infection.

Constipation A very common gastrointestinal disorder characterised by the passing of hard, dry bowel motions (stools) and difficulty of bowel motion.

Constitutive androstane receptor (CAR, NR113) Is a nuclear receptor transcription factor that regulates drug metabolism and homoeostasis.

Consumption Term used to describe wasting of tissues including but not limited to tuberculosis.

Consumptive Afflicted with or associated with pulmonary tuberculosis.

Contraceptive An agent that reduces the likelihood of or prevents conception.

Contraindication A condition which makes a particular treatment or procedure inadvisable.

Contralateral muscle Muscle of opposite limb (leg or arm).

Contralateral rotation Rotation occurring or originating in a corresponding part on an opposite side.

Contusion Another term for a bruise. A bruise, or contusion, is caused when blood vessels are damaged or broken as the result of a blow to the skin.

Convulsant A drug or physical disturbance that induces convulsion.

Convulsion Rapid and uncontrollable shaking of the body.

Coolant That which reduces body temperature.

Copper (Cu) Is essential in all plants and animals. It is found in a variety of enzymes including the copper centres of cytochrome C oxidase and the enzyme superoxide dismutase (containing copper and zinc). In addition to its enzymatic roles, copper is used for biological electron transport. Because of its role in facilitating iron uptake, copper deficiency can often produce anaemia-like symptoms. Dietary sources include curry powder, mushroom, nuts, seeds, wheat germ, whole grains and animal meat.

Copulation To engage in coitus or sexual intercourse. *adj*. copulatory.

Cor pulmonale Or pulmonary heart disease, is enlargement of the right ventricle of the heart as a response to high blood pressure or increased resistance in the lungs.

Cordial A preparation that is stimulating to the heart.

Corn Or callus, is a patch of hard, thickened skin on the foot that is formed in response to pressure or friction.

Corpora lutea A yellow, progesterone-secreting body that forms from an ovarian follicle after the release of a mature egg.

Corticosteroids A class of steroid hormones that are produced in the adrenal cortex, used clinically for hormone replacement therapy, for suppressing ACTH secretion, for suppression of immune response and as anti-neoplastic, anti-allergic and anti-inflammatory agents.

Corticosterone A 21-carbon steroid hormone of the corticosteroid type produced in the cortex of adrenal glands.

Cortisol Is a corticosteroid hormone made by adrenal glands.

Cornification Is the process of forming an epidermal barrier in stratified squamous epithelial tissue.

Coryza A word describing the symptoms of a head cold. It describes the inflammation of mucous membranes lining the nasal cavity which usually gives rise to the symptoms of nasal congestion and loss of smell, among other symptoms.

COX-1 See cyclooxygenase -1.

COX-2 See cyclooxygenase-2.

CpG islands Genomic regions that contain a high frequency of CpG sites.

CpG sites The cytosine-phosphate-guanine nucleotide that links two nucleosides together in DNA.

cPLA(2) Cytosolic phospholipases A2; these phospholipases are involved in cell-signalling processes such as inflammatory response.

CPY1B1, CPY1A1 A member of the cytochrome P450 superfamily of heme-thiolate monooxygenase enzymes.

Corticosterone A 21-carbon corticosteroid hormone produced in the cortex of adrenal glands that functions in the metabolism of carbohydrates and proteins.

Creatin A nitrogenous organic acid that occurs naturally in vertebrates and helps to supply energy to muscles.

Creatine phosphokinase (CPK, CK) Enzyme that catalyses the conversion of creatine and consumes adenosine triphosphate (ATP) to create phosphocreatine and adenosine diphosphate (ADP).

CREB cAMP response element-binding, a protein that is a transcription factor that binds to certain DNA sequences called cAMP response elements.

Crohn disease An inflammatory disease of the intestines that affects any part of the gastrointestinal tract.

CRP (C-reactive protein) A substance produced by the liver that increases in the presence of inflammation in the body.

Crossover study A longitudinal balance study in which participants receive a sequence of different treatments or exposures.

Croup Is an infection of the throat (larynx) and windpipe (trachea) that is caused by a virus (also called laryngotracheobronchitis).

Cryptococcal meningitis A fungal infection of the membranes covering the brain and spinal cord (meninges).

Crytochidism (cryptochism) A developmental defect characterised by the failure of one or both testes to move into the scrotum as the male fetus develops.

Curettage Surgical procedure in which a body cavity or tissue is scraped with a sharp instrument or aspirated with a cannula.

Cutaneous Pertaining to the skin.

CXC8 Also known as interleukin 8, IL-8.

Cyanogenesis Generation of cyanide. *adj*. cyanogenetic.

Cyclooxygenase (COX) An enzyme that is responsible for the formation of prostanoids – prostaglandins, prostacyclins and thromboxanes that are each involved in inflammatory response. Two different COX enzymes existed, now known as COX-1 and COX-2.

Cyclooxygenase-1 (COX-1) Is known to be present in most tissues. In the gastrointestinal tract, COX-1 maintains the normal lining of the stomach. The enzyme is also involved in kidney and platelet function.

Cyclooxygenase-2 (COX-2) Is primarily present at sites of inflammation.

Cysteine proteases Are enzymes that degrade polypeptides possessing a common catalytic mechanism that involves a nucleophilic cysteine thiol in a catalytic triad. They are found in fruit like papaya, pineapple and kiwifruit.

Cystitis A common urinary tract infection that occurs when bacteria travel up the urethra, infect the urine and inflame the bladder lining.

Cystorrhea Discharge of mucus from the bladder.

Cytochrome bc-1 complex Ubihydroquinone:cytochrome c oxidoreductase.

Cytochrome P450 3A CYP3A A very large and diverse superfamily of heme-thiolate proteins found in all domains of life. This group of enzymes catalyses many reactions involved in drug metabolism and synthesis of cholesterol, steroids and other lipids.

Cytokine Non-antibody proteins secreted by certain cells of the immune system which carry signals locally between cells. They are a category of signalling molecules that are used extensively in cellular communication.

Cytopathic Any detectable degenerative changes in the host cell due to infection.

Cytoprotective Protecting cells from noxious chemicals or other stimuli.

Cytosolic Relates to the fluid of the cytoplasm in cells.

Cytostatic Preventing the growth and proliferation of cells.

Cytotoxic Of or relating to substances that are toxic to cells, cell-killing.

D- galactosamine An amino sugar with unique hepatotoxic properties in animals.

Dandruff Scurf, dead, scaly skin among the hair.

Dartre Condition of dry, scaly skin

Debility Weakness, relaxation of muscular fibre.

Debridement Is the process of removing non-living tissue from pressure ulcers, burns and other wounds.

Debriding agent Substance that cleans and treats certain types of wounds, burns and ulcers.

Deciduogenic Relating to the uterus lining that is shed off at childbirth.

Deciduoma Decidual tissue induced in the uterus (as by trauma) in the absence of pregnancy.

Deciduomata Plural of deciduoma.

Decidual stromal cells Like endometrial glands and endothelium, they express integrins that bind basement components.

Decoction A medical preparation made by boiling the ingredients.

Decongestant A substance that relieves or reduces nasal or bronchial congestion.

Deep venous thrombosis Is a blood clot that forms in a vein deep inside a part of the body.

Defibrinated plasma Blood whose plasma component has had fibrinogen and fibrin removed.

Degranulation Cellular process that releases antimicrobial cytotoxic molecules from secretory vesicles called granules found inside some cells.

Delayed afterdepolarisations (DADs) Abnormal depolrisation that begins during phase 4 – after repolarisation is completed, but before another action potential would normally occur.

Delirium Is common, sudden severe confusion and rapid changes in brain function that occur with physical or mental illness; it is reversible and temporary.

Demulcent An agent that soothes internal membranes. Also called emollient.

Dendritic cells Are immune cells and form part of the mammalian immune system, functioning as antigen-presenting cells.

Dentition A term that describes all of the upper and lower teeth collectively.

Deobstruent A medicine which removes obstructions, also called an aperient.

Deoxypyridinoline (Dpd) A cross-link product of collagen molecules found in bone and excreted in urine during bone degradation.

Depilatory An agent for removing or destroying hair.

Depressant A substance that diminishes functional activity, usually by depressing the nervous system.

Depurative An agent used to cleanse or purify the blood, it eliminates toxins and purifies the system.

Dermatitis Inflammation of the skin causing discomfort, such as eczema.

Dermatitis herpetiformis An autoimmune chronic blistering skin disorder characterised by blisters filled with a watery fluid.

Dermatophyte A parasitic fungus on the skin.

Dermatosis Is a broad term that refers to any disease of the skin, especially one that is not accompanied by inflammation.

Dermonecrotic Pertaining to or causing necrosis of the skin.

Desquamation The shedding of the outer layers of the skin.

Desquamative ginginvitis Red, painful, glazed and friable gingivae which may be

a manifestation of some mucocutaneous conditions such as lichen planus or vesiculobullous disorders.

Detoxifier A substance that promotes the removal of toxins from a system or organ.

Diabetes A metabolic disorder associated with inadequate secretion or utilisation of insulin and characterised by frequent urination and persistent thirst. See diabetes mellitus.

Diabetes mellitus (DM) Sometimes called 'sugar diabetes', it is a set of chronic, metabolic disease conditions characterised by high blood sugar (glucose) levels that result from defects in insulin secretion, action or both. Diabetes mellitus appears in two forms.

Diabetes mellitus type I Formerly known as juvenile-onset diabetes, it is caused by deficiency of the pancreatic hormone insulin as a result of destruction of insulin-producing beta cells of the pancreas. Lack of insulin causes an increase of fasting blood glucose that begins to appear in the urine above the renal threshold.

Diabetes mellitus type II Formerly called non-insulin-dependent diabetes mellitus or adult-onset diabetes, the disorder is characterised by high blood glucose in the context of insulin resistance and relative insulin deficiency in which insulin is available but cannot be properly utilised.

Diabetic foot Any pathology that results directly from diabetes mellitus or any long-term or chronic complication of diabetes mellitus.

Diabetic neuropathy A neuropathic disorder that is associated with diabetes mellitus. It affects all peripheral nerves including pain fibres, motor neurons and the autonomic nervous system.

Diabetic retinopathy Damage to the retina caused by complications of diabetes mellitus, which can eventually lead to blindness.

Diads Two adjacent structural units in a polymer molecule.

Dialysis Is a method of removing toxic substances (impurities or wastes) from the blood when the kidneys are unable to do so.

Diaphoresis Is profuse sweating commonly associated with shock and other medical emergency conditions.

Diaphoretic A substance that induces perspiration. Also called sudorific.

Diaphyseal Pertaining to or affecting the shaft of a long bone (diaphysis).

Diaphysis The main or mid-section (shaft) of a long bone.

Diarrhoea A profuse, frequent and loose discharge from the bowels.

Diastolic Referring to the time when the heart is in a period of relaxation and dilatation (expansion). *cf.* systolic.

Dieresis Surgical separation of parts.

Dietary fibre Is a term that refers to a group of food components that pass through the stomach and small intestine undigested and reach the large intestine virtually unchanged. Scientific evidence suggests that a diet high in dietary fibre can be of value for treating or preventing such disorders as constipation, irritable bowel syndrome, diverticular disease, hiatus hernia and haemorrhoids. Some components of dietary fibre may also be of value in reducing the level of cholesterol in blood and thereby decreasing a risk factor for coronary heart disease and the development of gallstones. Dietary fibre is beneficial in the treatment of some diabetics.

Digalactosyl diglycerides Are major lipid components of chloroplasts.

Diosgenin A steroid-like substance that is involved in the production of the hormone progesterone, extracted from roots of *Dioscorea* yam.

Dipsia Sensation of dryness in the mouth and throat related to a desire to drink.

Dipsomania Pathological use of alcohol.

Discutient An agent (as a medicinal application) which serves to disperse morbid matter.

Disinfectant An agent that prevents the spread of infection, bacteria or communicable disease.

Distal sensory polyneuropathy (DSPN) Or peripheral neuropathy, is the most common neurological problem in HIV disease. DSPN also represents a complex symptom that occurs because of peripheral-nerve damage related to advanced HIV disease.

Diuresis Increased urination.

Diuretic A substance that increases urination (diuresis).

Diverticular disease Is a condition affecting the large bowel or colon and thought to be caused by eating too little fibre.

Diverticulitis Common, sometimes painful digestive disease which involves the formation of pouches (diverticula) within the bowel wall.

DMBA 7,12-Dimethylbenzanthracene. A polycyclic aromatic hydrocarbon found in tobacco smoke, which is a potent carcinogen.

DNA Deoxyribonucleic acid, a nucleic acid that contains the genetic instructions used in the development and functioning of all known living organisms.

DOCA Desoxycorticosterone acetate – a steroid chemical used as replacement therapy in Addison's disease.

Dopamine A catecholamine neurotransmitter that occurs in a wide variety of animals including both vertebrates and invertebrates.

Dopaminergic Relating to or activated by the neurotransmitter dopamine.

Double blind Refers to a clinical trial or experiment in which neither the subject nor the researcher knows which treatment any particular subject is receiving.

Douche A localised spray of liquid directed into a body cavity or onto a part.

DPPH 2,2 diphenyl -1- picryl-hydrazyl – a crystalline, stable free radical used as an inhibitor of free-radical reactions.

Dracunculiasis Also called guinea worm disease (GWD), is a parasitic infection caused by the nematode *Dracunculus medinensis*.

Dropsy An old term for the swelling of soft tissues due to the accumulation of excess water. *adj*. dropsical.

Drug-metabolising enzymes Play central roles in the biotransformation, metabolism and/or detoxification of xenobiotics or foreign compounds that are introduced into the human body.

Drusen Tiny yellow or white deposits of extracellular materials in the retina of the eye or on the optic nerve head.

DT diaphorase Also called DTD or NAD(P)H:quinone oxidoreductase, is an obligate two-electron reductase which bioactivates chemotherapeutic quinones.

Dysarthria Is a motor speech disorder.

Dysbiosis Also called dysbacteriosis, refers to a condition with microbial imbalances on or inside the body.

Dysentery Formerly known as flux or the bloody flux, is a disorder of the digestive system that results in severe diarrhoea containing mucus and blood in the feces. It is caused usually by a bacterium called *Shigella*.

Dysesthesia An unpleasant abnormal sensation produced by normal stimuli.

Dysgeusia Distortion of the sense of taste.

Dyshomeostasis An imbalance or other breakdown of a homeostasis system.

Dyskinesia The impairment of the power of voluntary movement resulting in fragmentary or incomplete movements. *adj*. dyskinetic.

Dyslipidemia Abnormality in or abnormal amount of lipids and lipoproteins in the blood.

Dysmenorrhea Is a menstrual condition characterised by severe and frequent menstrual cramps and pain associated with menstruation.

Dysmotility syndrome A vague descriptive term used to describe diseases of the muscles of the gastrointestinal tract (oesophagus, stomach and small and large intestines).

Dysosmia Qualitative alteration or distortion of the perception of smell.

Dyspareunia Painful sexual intercourse.

Dyspedia Indigestion followed by nausea.

Dyspepsia Refers to a complex symptom of epigastric pain or discomfort. It is often defined as chronic or recurrent discomfort centreed in the upper abdomen and can be caused by a variety of conditions. *cf*. functional dyspepsia.

Dysphagia Difficulty in swallowing.

Dysphonia A voice disorder, an impairment in the ability to produce voice sounds using vocal organs.

Dysplasia Refers to abnormality in development.

Dyspnoea Shortness of breath, difficulty in breathing.

Dysrhythmias See arrhythmias.

Dystocia Abnormal or difficult childbirth or labour.

Dystonia A neurological movement disorder characterised by prolonged, repetitive muscle contractions that may cause twisting or jerking movements of muscles.

Dysuria Refers to difficult and painful urination.

E-cadherin Has traditionally been categorised as a tumour suppressor.

E-selectin Also known as endothelial leukocyte adhesion molecule-1 (ELAM-1), CD62E, a

member of the selectin family. It is transiently expressed on vascular endothelial cells in response to IL-1 beta and TNF alpha.

EC 50 Median effective concentration that produces desired effects in 50% of the test population.

Ecbolic A drug (as an ergot alkaloid) that tends to increase uterine contractions and that is used especially to facilitate delivery.

Ecchymosis Skin discoloration caused by the escape of blood into the tissues from ruptured blood vessels.

ECG See electrocardiography.

EC–SOD Extracellular superoxide dismutase, a tissue enzyme mainly found in the extracellular matrix of tissues. It participates in the detoxification of reactive oxygen species by catalysing the dismutation of superoxide radicals.

Ectopic heartbeats Small changes in an otherwise normal heartbeat that lead to extra or skipped heartbeats.

Ectrodactyly Involves the absence of one or more central digits of the hand or foot.

Eczema Is broadly applied to a range of persistent skin conditions. These include dryness and recurring skin rashes which are characterised by one or more of these symptoms: redness, skin oedema, itching and dryness, crusting, flaking, blistering, cracking, oozing or bleeding.

Eczematous rash Dry, scaly, itchy rash.

ED 50 Is defined as the dose producing a response that is 50 % of the maximum obtainable.

Oedema Formerly known as dropsy or hydropsy, is characterised by swelling caused by abnormal accumulation of fluid beneath the skin or in one or more cavities of the body. It usually occurs in the feet, ankles and legs, but it can involve the entire body.

Oedematogenic Producing or causing oedema.

EGFR proteins Epidermal growth factor receptor (EGFR) proteins – Protein kinases are enzymes that transfer a phosphate group from a phosphate donor onto an acceptor amino acid in a substrate protein.

EGR-1 Early growth response 1, a human gene.

Eicosanoids Are signaling molecules made by oxygenation of arachidonic acid, a 20-carbon essential fatty acid, includes prostaglandins and related compounds.

Elastase A serine protease that also hydrolyses amides and esters.

Electrocardiography Or ECG, is a transthoracic interpretation of the electrical activity of the heart over time captured and externally recorded by skin electrodes.

Electromyogram (EMG) A test used to record the electrical activity of muscles. An electromyogram (EMG) is also called a myogram.

Electuary A medicinal paste composed of powders or other medical ingredients incorporated with sweeteners to hide the taste, suitable for oral administration.

Elephantiasis A disorder characterised by chronic thickened and oedematous tissue on the genitals and legs due to various causes.

Embrocation Lotion or liniment that relieves muscle or joint pains.

Embryonation Formation of embryo in the egg.

Embryotoxic Term that describes any chemical which is harmful to an embryo.

Emesis Vomiting, throwing up.

Emetic An agent that induces vomiting, *cf*: antiemetic.

Emetocathartic Causing vomiting and purging.

Emmenagogue A substance that stimulates, initiates and/or promotes menstrual flow. Emmenagogues are used in herbal medicine to balance and restore the normal function of the female reproductive system.

Emollient An agent that has a protective and soothing action on the surface of the skin and membranes.

Emphysema A long-term progressive disease of the lungs that primarily causes shortness of breath.

Emulsion A preparation formed by the suspension of very finely divided oily or resinous liquid in another liquid.

Encephalitis Inflammation of the brain caused by a virus.

Encephalocele Protrusion of brain tissue through a congenital fissure in the skull.

Encephalomalacia Cerebral softening, a localised softening of the brain substance due to haemorrhage or inflammation.

Encephalopathy A disorder or disease of the brain.

Endocrine *Adj*. Of or relating to endocrine glands or hormones secreted by them.

Endocytosis Is the process by which cells absorb material (molecules such as proteins) from outside the cell by engulfing it with their cell membrane.

Endometrial cancer Cancer that arises in the endometrium, the lining of the uterus (womb).

Endometriosis Is a common and often painful disorder of the female reproductive system in which the endometrium, the tissue that normally lines the womb (uterus), grows outside the uterus. The two most common symptoms of endometriosis are pain and infertility.

Endometritis Refers to inflammation of the endometrium, the inner lining of the uterus.

Endometrium The inner lining of the uterus.

Endoplasmic reticulum Is a network of tubules, vesicles and sacs around the nucleus that are interconnected.

Endostatin A naturally occurring 20-kDa C-terminal protein fragment derived from type-XVIII collagen. It is reported to serve as an anti-angiogenic agent that inhibits the formation of blood vessels that feed cancer tumours.

Endosteum The thin layer of cells lining the medullary cavity of a bone.

Endosteal Pertaining to the endosteum.

Endothelial progenitor cells Population of rare cells that circulate in the blood with the ability to differentiate into endothelial cells, cells that make up the lining of blood vessels.

Endothelin Any of a group of vasoconstrictive peptides produced by endothelial cells that constrict blood vessels and raise blood pressure.

Endotoxemia The presence of endotoxins in the blood, which may result in shock. *adj*. endotoxemic.

Endotoxin Toxins associated with certain bacteria unlike an 'exotoxin' that is not secreted in soluble form by live bacteria but is a structural component in bacteria which is released mainly when bacteria are lysed.

Enema Liquid injected into the rectum either as a purgative or medicine, also called clyster.

Enophthalmos A condition in which the eye falls back into the socket and inhibits proper eyelid function.

eNOS (Endothelial nitric oxide synthase) The enzyme responsible for most of the vascular nitric oxide produced.

Enteral Term used to describe the intestines or other parts of the digestive tract.

Enteralgia Pain in the intestines, intestinal colic.

Enteral administration Involves the oesophagus, stomach and small and large intestines (i.e. the gastrointestinal tract).

Enteritis Refers to inflammation of the small intestine.

Enterocolic disorder Inflamed-bowel disease.

Enterocytes Tall columnar cells in the small intestinal mucosa that are responsible for the final digestion and absorption of nutrients.

Enterohaemorrhagic Causing bloody diarrhoea and colitis, said of pathogenic microorganisms.

Enterohepatonephropathy Hepatorenal lesions accompanied by renal failure.

Enterolactone A lignin formed by the action of intestinal bacteria on lignan precursors found in plants, acts as a phytoestrogen.

Enteropooling Increased fluids and electrolytes within the lumen of the intestines due to increased levels of prostaglandins.

Enterotoxigenic Of or being an organism containing or producing an enterotoxin.

Enterotoxin Is a protein toxin released by a microorganism in the intestine.

Entheogen A substance taken to induce a spiritual experience.

Enuresis Bed-wetting, a disorder of elimination that involves the voluntary or involuntary release of urine into bedding, clothing or other inappropriate places.

Envenomation Is the entry of venom into a person's body, and it may cause localised or systemic poisoning.

Eosinophilia The state of having a high concentration of eosinophils (eosinophil granulocytes) in the blood.

Eosinophils Or, less commonly, acidophils, are white blood cells that are one of the immune-system components.

Epidermal growth factor receptor (EGFR) Belongs to the ErbB family of receptor tyrosine kinases (RTK). EGFRs are involved in the pathogenesis and progression of different carcinoma types.

Epididymis A structure within the scrotum attached to the backside of the testis and whose coiled duct provides storage, transit and maturation of spermatozoa.

Epididymitis A medical condition in which there is inflammation of the epididymis.

Epidural haematoma Accumulation of blood in the potential space between dura and bone, may be intracranial or spinal.

Epigastralgia Pain in the epigastric region.

Epigastric discomfort Bloated abdomen, swelling of abdomen, abdominal ditension.

Epilepsy A common chronic neurological disorder that is characterised by recurrent unprovoked seizures.

Epileptiform Resembling epilepsy or its manifestations. *adj*. epileptiformic.

Epileptogenesis A process by which a normal brain develops epilepsy, a chronic condition in which seizures occur. *adj*. epileptogenic.

Episiotomy A surgical incision through the perineum made to enlarge the vagina and assist childbirth.

Epithelial–mesenchymal transition or transformation (EMT) A process by which epithelial cells lose their cell polarity and cell–cell adhesion and gain migratory and invasive properties to become mesenchymal cells.

Epithelioma A usually benign skin disease most commonly occurring on the face, around the eyelids and on the scalp.

Epitope A single antigenic site on a protein against which an antibody reacts.

Epitrochlearis The most superficial muscle of the arm's anterior surface.

Epistaxis Acute haemorrhage from the nostril, nasal cavity or nasopharynx (nosebleed).

Epstein–Barr virus Herpes virus that is the causative agent of infectious mononucleosis. It is also associated with various types of human cancers.

ORbeta Oestrogen receptor beta, a nuclear receptor which is activated by the sex hormone oestrogen.

Ergocalciferol A form of vitamin D also called vitamin D2. See vitamin D.

Ergogenic Increasing capacity for bodily or mental labour especially by eliminating fatigue symptoms.

Ergonic Increasing capacity for bodily or mental labour especially by eliminating fatigue symptoms.

ERK (extracellular signal-regulated kinases) Widely expressed protein kinase intracellular signaling molecules which are involved in functions including the regulation of meiosis, mitosis and post-mitotic functions in differentiated cells.

Eructation The act of belching or of casting up wind from the stomach through the mouth.

Eruption A visible rash or cutaneous disruption.

Eryptosis Suicidal death of erythrocytes characterised by cell shrinkage, membrane blebbing, activation of proteases and phosphatidylserine exposure at the outer membrane leaflet.

Erysipelas Is an intensely red *Streptococcus* bacterial infection that occurs on the face and lower extremities.

Erythema Abnormal redness and inflammation of the skin due to vasodilation.

Erythema multiforme Is a skin disorder due to an allergic reaction or infection characterised by fever, general ill feeling, skin itching, joint aches and multiple skin lesions.

Erythematous Characterised by erythema.

Erythroleukoplakia An abnormal patch of red and white tissue that forms on mucous membranes in the mouth and may become cancer. Tobacco (smoking and chewing) and alcohol may increase the risk of erythroleukoplakia.

Erythropoiesis Is the process whereby erythroid precursor cells proliferate and differentiate into red blood cells.

Erythropoietin (EPO) A hormone produced by the kidney that promotes the formation of red blood cells (erythrocytes) in bone marrow.

Eschar A slough or piece of dead tissue that is cast off from the surface of the skin.

Escharotic Capable of producing an eschar, a caustic or corrosive agent.

Estradiol Is the predominant sex hormone present in females, also called oestradiol.

Oestrogen Female hormone produced by the ovaries that plays an important role in the oestrous cycle in women.

Oestrogen receptor (ER) Is a protein found in high concentrations in the cytoplasm of breast, uterus, hypothalamus and anterior hypophysis

cells; ER levels are measured to determine a breast CA's potential for response to hormonal manipulation.

Oestrogen receptor positive (ER+) Means that oestrogen is causing the tumour to grow and that the breast cancer should respond well to hormone suppression treatments.

Oestrogen receptor negative (ER−) Tumour is not driven by oestrogen and needs another test to determine the most effective treatment.

Oestrogenic Relating to oestrogen or producing oestrus.

Oestrus Sexual excitement or heat of female; the period of this is characterised by changes in sex organs.

Euglycaemia Normal blood glucose concentration.

Eupeptic Conducive to digestion.

Exanthema Sudden widespread rash.

Exanthematous Characterised by or of the nature of an eruption or rash.

Excitotoxicity Is the pathological process by which neurons are damaged and killed by glutamate and similar substances.

Excipient A pharmacologically inert substance used as a diluent or vehicle for active ingredients of a medication.

Exfoliative cheilitis Is a reactive process in which upper, lower or both lips become chronically inflamed, crusted and sometimes fissured.

Exocytosis The cellular process by which cells excrete waste products or chemical transmitters.

Exophthalmos or exophthalmia or proptosis Is a bulging of the eye anteriorly out of the orbit. *adj*. exophthalmic.

Exotoxin A toxin secreted by a microorganism and released into the medium in which it grows.

Expectorant An agent that increases bronchial mucous secretion by promoting liquefaction of the sticky mucus and expelling it from the body.

Experimental allergic encephalomyelitis (EAE) Is an animal model of brain inflammation.

Exteroceptive Responsiveness to stimuli that are external to an organism.

Extrapyramidal side effects Are a group of symptoms (tremor, slurred speech, akathisia, dystonia, anxiety, paranoia and bradyphrenia) that can occur in persons taking antipsychotic medications.

Extravasation Discharge or escape as of blood from the vein into surrounding tissues, discharge or escape from a vessel or channel.

Eyelid oedema Swollen eyelid caused by inflammation or excess fluid.

Fabry disease Is a rare X-linked (inherited) lysosomal storage disease caused by alpha-galactosidase. A deficiency which can cause a wide range of systemic symptoms such as pain in the extremities, papules on the lower body parts, cornea clouding, fatigue, neuropathy and renal and cardiac complications.

FAC chemotherapy Fluorouracil, doxorubicin (adriamycin) and cyclophosphamide chemotherapy.

FADD Fas-associated protein with death domain; the protein encoded by this gene is an adaptor molecule which interacts with other death cell surface receptors and mediates apoptotic signals.

Familial amyloid polyneuropathy (FAP) Also called Corino de Andrade's disease, a neurodegenerative autosomal dominant genetically transmitted, fatal, incurable disease.

Familial adenomatous polyposis (FAP) Is an inherited condition in which numerous polyps form mainly in the epithelium of the large intestine.

Familial dysautonomia A genetic disorder that affects the development and survival of autonomic and sensory nerve cells.

Fanconi syndrome Is a disease of the proximal renal tubes in which certain substances normally absorbed into the bloodstream by the kidneys are released into the urine instead.

FasL or CD95L Fas ligand is a type-II transmembrane protein that belongs to the tumour necrosis factor (TNF) family.

FAS: fatty acid synthase (FAS) A multienzyme that plays a key role in fatty acid synthesis.

Fas molecule A member of the tumour necrosis factor receptors that mediates apoptotic signals in many cell types.

Fauces The passage leading from the back of the mouth into the pharynx.

Favus A chronic skin infection, usually of the scalp, caused by the fungus *Trichophyton schoenleinii* and characterised by the development of thick yellow crusts over hair follicles. Also termed tinea favosa.

Febrifuge An agent that reduces fever. Also called an antipyretic.

Febrile Pertaining to or characterised by fever.

Febrile neutropenia The development of fever, often with other signs of infection, in an individual with neutropenia, an abnormally low number of neutrophil granulocytes in the blood.

Felon A purulent infection in the bulbous distal end of a finger.

Fetotoxic Toxic to the fetus.

Fibrates Hypolipidemic agents primarily used for decreasing serum triglycerides while increasing high-density lipoprotein (HDL).

Fibril A small slender fibre or filament.

Fibrin Insoluble protein that forms the essential portion of the blood clot.

Fibrinolysis A normal ongoing process that dissolves fibrin and results in the removal of small blood clots.

Fribinolytic Causing the dissolution of fibrin by enzymatic action.

Fibroblast Type of cell that synthesises the extracellular matrix and collagen, the structural framework (stroma) for animal tissues, and plays a critical role in wound healing.

Fibrogenic Promoting the development of fibres.

Fibromyalgia A common and complex chronic body-wide pain disorder that affects people physically, mentally and socially. Symptoms include debilitating fatigue, sleep disturbance and joint stiffness. Also referred to as FM or FMS.

Fibronectin A high–molecular weight (~440 kDa) glycoprotein of the extracellular matrix (ECM) that adheres to membrane-spanning receptor proteins called integrins.

Fibrosarcoma A malignant tumour derived from fibrous connective tissue and characterised by immature proliferating fibroblasts or undifferentiated anaplastic spindle cells.

Fibrosis The formation of fibrous tissue as a reparative or reactive process.

Filarial Pertaining to a thread-like nematode worm.

Filariasis A parasitic and infectious tropical disease that is caused by thread-like filarial nematode worms in the superfamily *Filarioidea*.

Fistula An abnormal connection between two organs inside the body.

Fistula-in-ano A track connecting the internal anal canal to the skin surrounding the anal orifice.

5′-Nucleotidase 5′-ribonucleotide phosphohydrolase, an intrinsic membrane glycoprotein present as an ectoenzyme in a wide variety of mammalian cells, hydrolyses 5′-nucleotides to their corresponding nucleosides.

5-HT1A receptor A serotonin protein that binds to 5-5-hydroxytryptamine (5-HT) with high affinity to exert subtle control over emotion and behaviour.

Flash electroretinogram or Flash ERG (fERG) Is a test which measures the electrical response of the eye's light-sensitive cells (rods and cones). It also checks other cell layers in the retina.

Flatulence Is the presence of a mixture of gases known as flatus in the digestive tract of mammals expelled from the rectum. Excessive flatulence can be caused by lactose intolerance, certain foods or a sudden switch to a high fibre.

Flavans A sub-group of flavonoids. See flavonoids.

Flavanols A subgroup of flavonoids, are a class of flavonoids that use the 2-phenyl-3,4-dihydro-2H-chromen-3-ol skeleton. These compounds include catechins and catechin gallates. They are found in chocolate, fruit and vegetables. See flavonoids.

Flavanones A sub-group of flavonoids, constitute >90 % of total flavonoids in citrus. The major dietary flavanones are hesperetin, naringenin and eriodictyol.

Flavivirus A family of viruses transmitted by mosquitoes and ticks that cause some important diseases including dengue, yellow fever, tick-borne encephalitis and West Nile fever.

Flavones A sub-group of flavonoids based on the backbone of 2-phenylchromen-4-one

(2-phenyl-1-benzopyran-4-one). Flavones are mainly found in cereals and herbs.

Flavonoids Or bioflavonoids are a group of polyphenolic antioxidant compounds that occur in plants as secondary metabolites. They are responsible for the colour of fruit and vegetables. Twelve basic classes (chemical types) of flavonoids have been recognised: flavones, isoflavones, flavans, flavanones, flavanols, flavanolols, anthocyanidins, catechins (including proanthocyanidins), leukoanthocyanidins, chalcones, dihydrochalcones and aurones. Apart from their antioxidant activity, flavonoids are known for their ability to strengthen capillary walls, thus assisting circulation and helping to prevent and treat bruising, varicose veins, bleeding gums and nosebleeds and heavy menstrual bleeding and are also anti-inflammatory.

Fluorine F is an essential chemical element that is required for maintenance of healthy bones and teeth and to reduce tooth decay. It is found in sea weeds, tea, water, seafood and dairy products.

Fluorosis A dental health condition caused by a child receiving too much fluoride during tooth development.

Flux An excessive discharge of fluid.

FMD (flow-mediated dilation) A measure of endothelial dysfunction which is used to evaluate cardiovascular risk. Also called FMVD (flow-mediated vasodilation).

Focal adhesion kinase (FAK) Is a protein tyrosine kinase which is recruited at an early stage to focal adhesions and which mediates many of the downstream regulatory responses.

follicle-stimulating hormone (FSH) A hormone produced by the pituitary gland. In women, it helps control the menstrual cycle and the production of eggs by the ovaries.

Follicular atresia The breakdown of ovarian follicles.

Fomentation Treatment by the application of warm, moist substance.

Fontanelle Soft spot on an infant's skull.

Forkhead box-O transcription factors (FOXOs) Are a family of transcription factors that play important roles in regulating the expression of genes involved in cell growth, proliferation, differentiation and longevity. It also plays an important role in tumour suppression by regulating the expression of genes involved in stress resistance, DNA damage repair, cell cycle arrest and apoptosis.

Framboesia See yaws.

FRAP Ferric reducing ability of plasma, an assay used to assess antioxidant property.

Friedreich's ataxia Is a genetic inherited disorder that causes progressive damage to the nervous system resulting in symptoms ranging from muscle weakness and speech problems to heart disease. *cf.* ataxia.

Fulminant hepatitis Acute liver failure.

Functional dyspepsia A non-ulcer condition that causes an upset stomach or pain or discomfort in the upper belly near the ribs.

Functional food Is any fresh or processed food claimed to have a health-promoting or disease-preventing property beyond the basic function of supplying nutrients. Also called medicinal food.

Furuncle Is a skin disease caused by the infection of hair follicles usually caused by *Staphylococcus aureus* resulting in the localised accumulation of pus and dead tissue.

Furunculosis Skin condition characterised by persistent, recurring boils.

G protein-coupled receptor kinases (GRKs, GPCRKs) A family of protein kinases which regulate the activity of G protein-coupled receptors (GPCRs) by phosphorylating their intracellular domains after their associated G proteins have been released and activated.

GABA Gamma aminobutyric acid required as an inhibitory neurotransmitter to block the transmission of an impulse from one cell to another in the central nervous system, which prevents over-firing of nerve cells. It is used to treat both epilepsy and hypertension.

GADD 152 A pro-apoptotic gene.

Galactifuge Or lactifuge, casuing the arrest of milk secretion.

Galactogogue A substance that promotes the flow of milk.

Galactophoritis Inflammation of milk ducts.

Galactopoietic Increasing the flow of milk, milk-producing.

Gall baldder A small, pear-shaped muscular sac located under the right lobe of the liver in which bile secreted by the liver is stored until

needed by the body for digestion. Also called cholecyst, cholecystis.

gallic acid equivalent (GAE) Measures the total phenol content in terms of the standard gallic acid by the Folin–Ciocalteau assay.

Galphai proteins or G alpha I proteins Are heterotrimeric guanine nucleotide-regulatory (G) proteins associated with a variety of intracellular membranes and specific plasma membrane domains.

Gamma GT (GGT) Gamma-glutamyl transpeptidase, a liver enzyme.

Gastralgia (Heart Burn) Pain in the stomach or abdominal region. It is caused by excess acid or an accumulation of gas in the stomach.

Gastric Pertaining to or affecting the stomach.

Gastric emptying Refers to the speed at which food and drink leave the stomach.

Gastritis Inflammation of the stomach.

Gastrocnemius muscle The big calf muscle at the rear of the lower leg.

Gastrodynia Pain in the stomach.

Gastroprokinetic See prokinetic.

Gastrotonic (gastroprotective) Substance that strengthens, tones or regulates gastric functions (or protects from injury) without overt stimulation or depression.

Gavage Forced feeding.

Gene silencing Suppression of the expression of a gene.

Genotoxic Describes a poisonous substance which harms an organism by damaging its DNA, thereby capable of causing mutations or cancer.

Genotoxin A chemical or other agent that damages cellular DNA resulting in mutations or cancer.

Geriatrics Is a sub-specialty of internal medicine that focuses on health care of elderly people.

Gestational hypertension Development of arterial hypertension in a pregnant woman after 20 weeks gestation.

Ghrelin A gastrointestinal peptide hormone secreted by epithelial cells in the stomach lining; it stimulates appetite and gastric emptying and increases cardiac output.

Gingival index An index describing the clinical severity of gingival inflammation as well as its location.

Gingivitis Refers to gingival inflammation induced by bacterial biofilms (also called plaque) adherent to tooth surfaces.

Gin-nan sitotoxism Toxicity caused by ingestion of ginkgotoxin and characterised mainly by epileptic convulsions, paralysis of the legs and loss of consciousness.

GIP Gastric inhibitory polypeptide, also known as glucose-dependent insulinotropic peptide, a member of the secretin family of hormones.

Glaucoma A group of eye diseases in which the optic nerve at the back of the eye is slowly destroyed, leading to impaired vision and blindness.

Gleet A chronic inflammation (as gonorrhoea) of a bodily orifice usually accompanied by an abnormal discharge.

Glial cells Support, non-neuronal cells in the central nervous system that maintain homeostasis, form myelin and provide protection for the brain's neurons.

Glioma Is a type of tumour that starts in the brain or spine. It is called a glioma because it arises from glial cells.

Glioblastoma Common and most lethal form of brain tumour.

Glioblastoma multiforme Most common and most aggressive type of primary brain tumour in humans involving glial cells.

Glomerulonephritis (GN) A renal disease characterised by inflammation of the glomeruli, or small blood vessels in the kidneys. Also known as glomerular nephritis. *adj*. glomerulonephritic.

Glomerulosclerosis A hardening (fibrosis) of the glomerulus in the kidney.

Glossal Pertaining to the tongue.

GLP-1 Glucagon-like peptide-1.

Glucagon-like peptide-1 (GLP-1) Is derived from the transcription product of the proglucagon gene, reduces insulin requirement in diabetes mellitus and promotes satiety.

Gluconeogenesis A metabolic pathway that results in the generation of glucose from non-carbohydrate carbon substrates such as lactate. *adj*. gluconeogenic.

Glucose-6-phosphate dehydrogenase (G6PD or G6PDH) Is a cytosolic enzyme in the pentose phosphate metabolic pathway.

Glucose transporter type 4 (GLUT 4) Insulin-regulated glucose transporter found in adipose

tissues and striated muscles that modulates insulin-related translocation into the cell.

Glucose transporters GLUT or SLC2A family are a family of membrane proteins found in most mammalian cells.

Glucosuria or glycosuria Is the excretion of glucose into urine.

Glucosyltranferase An enzyme that enables the transfer of glucose.

Glucuronidation A phase II detoxification pathway occurring in the liver in which glucuronic acid is conjugated with toxins.

Glutamic oxaloacetate transaminase (GOT) Catalyses the transfer of an amino group from an amino acid (Glu) to a 2-keto-acid to generate a new amino acid and the residual 2-keto-acid of the donor amino acid.

Glutamic pyruvate transaminase (GPT) See Alanine aminotransferase.

Glutathione (GSH) A tripeptide produced in the human liver, plays a key role in intermediary metabolism, immune response and health. It plays an important role in scavenging free radicals and protects cells against several toxic oxygen-derived chemical species.

Glutathione peroxidase (GPX) The general name of an enzyme family with peroxidase activity whose main biological role is to protect the organism from oxidative damage.

Glutathione S-transferase (GST) A major group of detoxification enzymes that participate in the detoxification of reactive electrophilic compounds by catalysing their conjugation to glutathione.

Glycaemic index (GI) Measures carbohydrates according to how quickly they are absorbed and raise the glucose level of the blood.

Glycaemic load (GL) Is a ranking sytem for carbohydrate content in food portions based on their glycaemic index and the amount of available carbohydrate, i.e. GI x available carbohydrate / 100. Glycaemic load combines both the quality and quantity of carbohydrates in one 'number'. It is the best way to predict blood glucose values of different types and amounts of food.

Glycation or glycosylation A chemical reaction in which glycosyl groups are added to a protein to produce a glycoprotein.

Glycogenolysis Is the catabolism of glycogen by removal of a glucose monomer through cleavage with inorganic phosphate to produce glucose-1-phosphate.

Glycometabolism Metabolism (oxidation) of glucose to produce energy.

Glycosuria Or glucosuria, is an abnormal condition of osmotic diuresis due to excretion of glucose by the kidneys into the urine.

Glycosylases A family of enzymes involved in base excision repair.

Goitre An enlargement of the thyroid gland leading to swelling of the neck or larynx.

Goitrogen Substance that suppresses the function of the thyroid gland by interfering with iodine uptake causing enlargement of the thyroid, i.e. goitre.

Goitrogenic *Adj*. causing goitre.

Gonadotroph A basophilic cell of the anterior pituitary specialised to secrete a follicle-stimulating hormone or luteinising hormone.

Gonatropins Protein hormones secreted by gonadotrope cells of the pituitary gland of vertebrates.

Gonorrhoea A common sexually transmitted bacterial infection caused by the bacterium *Neisseria gonorrhoeae*.

Gout A disorder caused by a build-up of a waste product, uric acid, in the bloodstream. Excess uric acid settles in joints causing inflammation, pain and swelling.

G-protein-coupled receptors (GPCRs) Constitute the largest family of cell-surface molecules involved in signal transmission. These receptors play key physiological roles, and their dysfunction results in several diseases.

Granulation The condition or appearance of being granulated (becoming grain-like).

Gravel Sand-like concretions of uric acid, calcium oxalate and mineral salts formed in the passages of the biliary and urinary tracts.

Gripe water Is a home remedy for babies with colic, gas, teething pain or other stomach ailments. Its ingredients vary and may include alcohol, bicarbonate, ginger, dill, fennel and chamomile.

Grippe An epidemic catarrh; older term for influenza.

GSH See Glutathione.

GSH-Px Glutathione peroxidase, general name of an enzyme family with peroxidase activity whose main biological role is to protect the organism from oxidative damage.

GSSG Glutathione disulfides are biologically important intracellular thiols, and alterations in the GSH/GSSG ratio are often used to assess exposure of cells to oxidative stress.

GSTM Glutathione S transferase M1, a major group of detoxification enzymes.

GSTM 2 Glutathione S transferase M2, a major group of detoxification enzymes.

G2-M cell cycle The phase where the cell prepares for mitosis and where chromatids and daughter cells separate.

Guillain–Barre syndrome Is a serious disorder that occurs when the body's defense (immune) system mistakenly attacks part of the nervous system leading to nerve inflammation, muscle weakness and other symptoms.

Gynecomastia Enlargement of the gland tissue of the male breast resulting from an imbalance of hormones.

Gynecopathy Any or various diseases specific to women.

Gynoid adiposity Fat distribution mainly to the hips and thighs, pear shaped.

Haemagogic Promoting a flow of blood.

Haematemesis Is the vomiting of blood.

Haematinic Improving the quality of blood, its haemoglobin level and the number of erythrocytes.

Haematochezia Passage of stools containing blood.

Haematochyluria The discharge of blood and chyle (emulsified fat) in urine, see also chyluria.

Haematoma A localised accumulation of blood in a tissue or space composed of clotted blood.

Haematometra A medical condition involving bleeding of or near the uterus.

Haematopoiesis Formation of blood cellular components from haematopoietic stem cells.

Haematopoietic *Adj*. Relating to the formation and development of blood cells.

Haematuria Is the presence of blood in urine. Haematuria is a sign that something is causing abnormal bleeding in a person's genitourinary tract.

Haeme oxygenase (HO-1, encoded by Hmox1) is an inducible protein activated in systemic inflammatory conditions by oxidant stress, an enzyme that catalyses degradation of haem.

Haemochromatosis Iron overload in the body with a hereditary or primary cause.

Haemodialysis A method for removing waste products such as potassium and urea as well as free water from blood when the kidneys are in renal failure.

Haemolysis Lysis of red blood cells and the release of haemoglobin into surrounding fluid (plasma). *adj*. haemolytic.

Haemoptysis Is the coughing up of blood from the respiratory tract. The blood can come from the nose, mouth, throat and airway passages leading to the lungs.

Haemorrhage Bleeding, discharge of blood from blood vessels.

Haemorrhoids A painful condition in which the veins around the anus or lower rectum are enlarged, swollen and inflamed. Also called piles.

Haemostasis A complex process which causes the bleeding process to stop.

Haemostatic Something that stops bleeding.

Halitosis (Bad breath) a common condition caused by sulphur-producing bacteria that live within the surface of the tongue and in the throat.

Hallucinogen Drug that produces hallucination.

Hallucinogenic Inducing hallucinations.

Hallux abducto valgus Commonly called bunion, is an abnormal bending of the big toe towards the other toes of the foot.

Haplotype A set of alleles of closely linked loci on a chromosome that tend to be inherited together.

Hapten A small molecule that can elicit an immune response only when attached to a large carrier such as a protein.

HATs Histone acetyl transferases, enzymes that regulate the acetylation of histones and transcription factors, playing a major role in the growth and differentiation of cells.

HbA1c Glycosylated haemoglobin.

HBeAg Hepatitis B e antigen.

HBsAg Hepatitis B s antigen.

HBD-2 (human β-defensin 2) A member of the defensin family of antimicrobial peptides

that plays important roles in the innate and adaptive immune system of both vertebrates and invertebrates.

Heartburn Burning sensation in the stomach and oesophagus caused by excessive acidity of stomach fluids.

Heat rash Any condition aggravated by heat or hot weather such as intertrigo.

Heat shock chaperones (HSC) Ubiquitous molecules involved in the modulation of protein conformational and complexation states associated with heat stress or other cellular stress response.

Heat shock proteins (HSP) A group of functionally related proteins, the expression of which is increased when cells are exposed to elevated temperatures or other cellular stresses.

Haelminthiasis A disease in which a part of the body is infested with worms such as pinworm, roundworm or tapeworm.

Haemagglutination A specific form of agglutination that involves red blood cells.

Haemagglutination inhibition test Measures the ability of soluble antigen to inhibit the agglutination of antigen-coated red blood cells by antibodies.

Haemagglutinin Refers to a substance that causes red blood cells to agglutinate.

Haemangioma Blood vessel.

Haematocrit Is a blood test that measures the percentage of the volume of whole blood that is made up of red blood cells.

Haematopoietic Pertaining to the formation of blood or blood cells.

Haematopoietic stem cell Is a cell isolated from blood or bone marrow that can renew itself and differentiate to a variety of specialised cells.

Haem oxygenase-1 (HO-1) An enzyme that catalyses the degradation of haem, an inducible stress protein, confers cytoprotection against oxidative stress in-vitro and in-vivo.

Haemoglobinopathies Genetic defects that produce abnormal haemoglobins and anaemia.

Haemolytic anaemia Anaemia due to haemolysis, the breakdown of red blood cells in blood vessels or elsewhere in the body.

Haemorheology Study of blood flow and its elements in the circulatory system. *adj*. haemorheological.

Haemorrhagic colitis An acute gastroenteritis characterised by overtly bloody diarrhoea that is caused by *Escherichia coli* infection.

Haemolysin Certain proteins and lipids that cause lysis of red blood cells by damaging their cell membranes.

Haemolytic–uremic syndrome Is a disease characterised by haemolytic anaemia, acute renal failure (uremia) and a low platelet count.

Hepa-1c1c7 A type of hepatoma cells.

Hepatalgia Pain or discomfort in the liver area.

Hepatomegaly Condition of enlarged liver.

Hepatectomy The surgical removal of part or all of the liver.

Hepatic Relating to the liver.

Hepatic cirrhosis Affecting the liver, characterised by hepatic fibrosis and regenerative nodules.

Hepatic fibrosis Is overly profuse wound healing in which excessive connective tissue builds up in the liver.

Hepatitis Inflammation of the liver.

Hepatitis A Formerly known as infectious hepatitis, is an acute infectious disease of the liver caused by the hepatovirus hepatitis A virus.

Hepatocarcinogenesis Represents a linear and progressive cancerous process in the liver in which successively more aberrant monoclonal populations of hepatocytes evolve.

Hepatocellular carcinoma (HCC) Also called malignant hepatoma, is a primary malignancy (cancer) of the liver.

Hepatocytolysis Cytotoxicity (dissolution) of liver cells.

Hepatoma Cancer of the liver.

Hepatopathy A disease or disorder of the liver.

Hepatoprotective Liver protector, a substance that helps protect the liver from damage by toxins, chemicals or other disease processes.

Hepatoregenerative A compound that promotes hepatocellular regeneration and repairs and restores liver function to optimum performance.

Hepatotonic Liver tonic, a substance that is tonic to the liver – usually employed to normalize liver enzymes and function.

Hernia Occurs when part of an internal organ bulges through a weak area of muscle.

HER- 2 Human epidermal growth factor receptor 2, a protein giving higher aggressiveness in breast cancer, also known as ErbB-2, ERBB2.

Herpes A chronic inflammation of the skin or mucous membrane characterised by the development of vesicles on an inflammatory base.

Herpes circinatus Dermatitis herpetiformis (resembling herpes).

Herpes simplex virus 1 and 2 – (HSV-1 and HSV-2) Are two species of the herpes virus family which cause a variety of illnesses/infections in humans such as cold sores, chickenpox or varicella, shingles or herpes zoster (VZV), cytomegalovirus (CMV) and various cancers and can cause brain inflammation (encephalitis). HSV-1 is commonly associated with herpes outbreaks of the face known as cold sores or fever blisters, whereas HSV-2 is more often associated with genital herpes. They are also called human herpes virus 1 and 2 (HHV-1 and HHV-2) and are neurotropic and neuroinvasive viruses; they enter and hide in the human nervous system, accounting for their durability in the human body.

Herpes zoster Or simply zoster, commonly known as shingles and also known as zona, is a viral disease characterised by a painful skin rash with blisters.

Herpes zoster ophthalmicus (HZO) Is a viral ocular disease characterised by a painful skin rash in one or more dermatome distributions of the fifth cranial nerve, shared by the eye and orbit.

Heterophobia Term used to describe irrational fear of, aversion to or discrimination against heterosexuals.

HDL-C (HDL cholesterol) High-density lipoprotein cholesterol, also called 'good cholesterol'. See also high-density lipoprotein.

Hiatus hernia Occurs when the upper part of the stomach pushes its way through a tear in the diaphragm.

High-density lipoprotein (HDL) Is one of the five major groups of lipoproteins which enable cholesterol and triglycerides to be transported within the water-based bloodstream. HDL can remove cholesterol from atheroma within arteries and transport it back to the liver for excretion or re-utilisation – which is the main reason why HDL-bound cholesterol is sometimes called 'good cholesterol', or HDL-C. A high level of HDL-C seems to protect against cardiovascular diseases. *cf.* LDL.

HGPRT, HPRT (hypoxanthine-guanine phosphoribosyltransferase) An enzyme that catalyses the conversion of 5-phosphoribosyl-1-pyrophosphate and hypoxanthine, guanine or 6-mercaptopurine to the corresponding 5′-mononucleotides and pyrophosphate. The enzyme is important in purine biosynthesis as well as central nervous system functions.

Hippocampus A ridge in the floor of each lateral ventricle of the brain that consists mainly of grey matter.

Hippocampal Pertaining to the hippocampus.

Hirsutism A condition where women have excess facial and body hair that is dark and coarse.

Histaminergic Liberated or activated by histamine, relating to the effects of histamine at histamine receptors of target tissues.

Histaminergic receptors Are types of G-protein-coupled receptors with histamine as their endogenous ligand.

Histone acetyltransferases (HATs) Are enzymes that acetylate conserved lysine amino acids on histone proteins by transferring an acetyl group from acetyl CoA to form e-N-acetyl lysine. HATs act as transcriptional co-activators.

Histone lysine demethylases (KDMs) Enymes that play a key role in the amplification of hypoxia-inducible-factor signalling and expression of pro-angiogenic genes in cancer and neurological disorders.

HIV See Human immunodeficiency virus.

Hives (Urticaria) is a skin rash characterised by circular wheals of reddened and itching skin.

HLA Human leukocyte antigen system, name of the major histocompatibility complex (MHC) in humans.

HLA-DQB1 Human leucocyte antigen beta chain.

HLA-DR A major histocompatibility complex (MHC) class II cell surface receptor encoded by the human leukocyte antigen complex on chromosome 6 region 6p21.31.

HMG-CoAr 3-hydroxy-3-methyl-glutaryl-CoA reductase or (HMGCR) is the rate-controlling enzyme (EC 1.1.1.88) of the mevalonate pathway.

HMG-CoA 3-hydroxy-3-methylglutaryl-coenzyme A, an intermediate in the mevalonate pathway.

Hodgkin's disease Disease characterised by enlargement of the lymph glands and spleen and by anaemia.

Homeodomain transcription factor A protein domain encoded by a homeobox. Homeobox genes encode transcription factors which typically switch on cascades of other genes.

Homeostasis The maintenance of a constant internal environment of a cell or an organism despite fluctuations in the external.

Homeotherapy Treatment or prevention of disease with a substance similar but not identical to the causative agent of the disease.

Homocysteine An amino acid in the blood.

Homograft See allograft.

Hormesis A term used by toxicologists to refer to a biphasic dose response to an environmental agent characterised by a low-dose stimulation or beneficial effect and a high-dose inhibitory or toxic effect.

Hormonal (female) Substance that has a hormone-like effect similar to that of oestrogen and/or a substance used to normalise female hormone levels.

Hormonal (male) Substance that has a hormone-like effect similar to that of testosterone and/or a substance used to normalise male hormone levels.

HRT Hormone replacement therapy, the administration of the female hormones oestrogen and progesterone and sometimes testosterone.

HSF-1 factor Major regulator of heat shock protein transcription in eukaryotes.

HSP27 Is an ATP-independent, 27 kDa heat shock protein chaperone that confers protection against apoptosis.

HSP70 Heat shock protein chaperone that confers protection against heat-induced apoptosis.

HSP90 A 90 kDa heat shock protein chaperone that has the ability to regulate a specific subset of cellular signalling proteins that have been implicated in disease processes.

HSPD 1 Heat shock 60 kDa protein 1

hTERT – (TERT) Telomerase reverse transcriptase is a catalytic sub-unit of the enzyme telomerase in humans. It exerts a novel protective function by binding to mitochondrial DNA, increasing respiratory chain activity and protecting against oxidative stress–induced damage.

HT29 cells Are human intestinal epithelial cells which produce the secretory component of immunoglobulin A (IgA) and carcinoembryonic antigen (CEA).

Human cytomegalovirus (HCMV) A DNA herpes virus which is the leading cause of congenital viral infection and mental retardation.

Human factor X A coagulation factor also known by the eponym Stuart–Prower factor or as thrombokinase, is an enzyme involved in blood coagulation. It is synthesised in the liver and requires vitamin K for its synthesis.

Human immunodeficiency virus (HIV) A retrovirus that can lead to acquired immunodeficiency syndrome (AIDS), a condition in humans in which the immune system begins to fail, leading to life-threatening opportunistic infections.

Humoral immune response (HIR) Is the aspect of immunity that is mediated by secreted antibodies (as opposed to cell-mediated immunity, which involves T lymphocytes) produced in the cells of the B lymphocyte lineage (B cell).

HUVEC Human umbilical vein endothelial cells.

Hyaluronidase Enzymes that catalyse the hydrolysis of certain complex carbohydrates like hyaluronic acid and chondroitin sulphates.

Hydatidiform A rare mass or growth that forms inside the uterus at the beginning of pregnancy.

Hydrocele Abnormal accumulation of fluid inside the scrotum.

Hydrocholeretic An agent that stimulates an increased output of bile of low specific gravity.

Hydrogogue A purgative that causes an abundant watery discharge from the bowel.

Hydronephrosis Is distension and dilation of the renal pelvis and calyces usually caused by obstruction of the free flow of urine from the kidney.

Hydrophobia A viral neuro-invasive disease that causes acute encephalitis (inflammation of the brain) in warm-blooded animals. Also called rabies.

Hydropsy See dropsy.

Hydrothorax Accumulation of serous fluid in the pleural cavity.

Hyperaemia The increase of blood flow to different tissues in the body.

Hyperalgesia An increased sensitivity to pain (enhanced pricking pain) which may be caused by damage to nociceptors or peripheral nerves.

Hyperammonaemia A metabolic disturbance characterised by an excess of ammonia in the blood.

Hypercalciuria (*Idiopathic*) presence of excess calcium in the urine without obvious cause.

Hypercholesterolemia High levels of cholesterol in the blood that increase a person's risk for cardiovascular disease leading to stroke or heart attack.

Hyperemia Is the increased blood flow that occurs when tissue is active.

Hyperemesis Severe and persistent nausea and vomiting (morning sickness) during pregnancy.

Hyperfibrinogenemia Excessive fibrinogen in the blood.

Hyperglycaemia High blood sugar; is a condition in which an excessive amount of glucose circulates in the blood plasma.

Hyperglycaemic A substance that raises blood sugar levels.

Hyperhomocysteinemia Is a medical condition characterised by an abnormally large level of homocysteine in the blood.

Hyperinsulinemia A condition in which there are excess levels of circulating insulin in the blood; also known as pre-diabetes.

Hyperkalemia Is an elevated blood level of the electrolyte potassium.

Hyperkeratosis Abnormal thickening of the outer layer of the skin. adj hyperkeratotic.

Hyperknesis Enhanced itch to pricking.

Hyperleptinemia Increased serum leptin level.

Hyperlipoproteinemia A metabolic disorder characterised by abnormally elevated concentrations of lipid/lipoprotein in the plasma; also known as hyperlipidemia and hyperlipemia.

Hypermenorrhoea Abnormally heavy or prolonged menstruation.

Hypermethylation An increase in the inherited methylation of cytosine and adenosine residues in DNA.

Hyperoxaluria An excessive urinary excretion of oxalate.

Hyperphagia Or polyphagia, abnormally large ingestion of food beyond that needed for basic energy requirements.

Hyperpiesia Persistent and pathological high blood pressure for which no specific cause can be found.

Hyperplasia Increased cell production in a normal tissue or organ.

Hyperprebeta-lipoproteinaemia Increased concentrations of pre-beta-lipoproteins in the blood.

Hyperpropulsion Using water pressure as a force to move objects; used to dislodge calculi in the urethra.

Hyperpyrexia Is an abnormally high fever.

Hypertension Commonly referred to as 'high blood pressure' or HTN, is a medical condition in which the arterial blood pressure is chronically elevated.

Hypertensive Characterised or caused by increased tension or pressure as abnormally high blood pressure.

Hypertonia Abnormal increase in muscle tension and a reduced ability of the muscle to stretch.

Hypertriglyceridaemia or hypertriglyceemia A disorder that causes high triglycerides in the blood.

Hypertrophy Enlargement or overgrowth of an organ.

Hyperuricemia Is a condition characterised by abnormally high levels of uric acid in the blood.

Hypoadiponectinemia The state of having too low levels of adiponectin, a major metabolic endocrine, responsible for regulating things like glucose uptake and lipolysis (the breakdown of fat deposits); low adiponectin is a risk factor for both type II diabetes and metabolic syndrome.

Hypoalbuminemia A medical condition where levels of albumin in blood serum are abnormally low.

Hypocalcemic tetany A disease caused by an abnormally low level of calcium in the blood and characterised by hyperexcitability of the neuromuscular system and results in carpopedal spasms.

Hypochlorhydria Refers to states where the production of gastric acid in the stomach is absent or low.

Hypocholesterolemic Cholesterol reducer, a substance that lowers blood cholesterol levels.

Hypocitraturia Low amount of citrate in the urine, an important risk factor for kidney stone formation.

Hypocorticism See Addison's disease.

Hypocortisolism See Addison's disease.

Hypoesthesia Or hypesthesia, refers to a reduced sense of touch or sensation or a partial loss of sensitivity to sensory stimuli.

Hypoglycemic An agent that lowers the concentration of glucose (sugar) in the blood.

Hypogonadism syndrome Characterised by defects of the gonads.

Hypoperfusion Decreased blood flow through an organ characterised by an imbalance of oxygen demand and oxygen delivery to tissues.

Hypophagic Under-eating.

Hypophysectomy The surgical removal of the hypophysis (pituitary gland).

Hypospadias An abnormal birth defect in males in which the urethra opens on the under surface of the penis.

Hypotensive Characterised by or causing diminished tension or pressure as abnormally low blood pressure.

Hypothermia A condition in which an organism's temperature drops below that required for normal metabolism and body functions.

Hypothermic Relating to hypothermia, with subnormal body temperature.

Hypoxaemia Is the reduction of oxygen specifically in the blood.

Hypoxia A shortage of oxygen in the body. *adj*. hypoxic.

Hypoxia-inducible factors (HIFs) Transcription factors that respond to changes in available oxygen in the cellular environment, specifically to deficiency in oxygen.

ICAM-1 (inter-cellular adhesion molecule 1) Also known as CD54 (cluster of differentiation 54), is a protein that in humans is encoded by the ICAM1 gene.

IC50 The median maximal inhibitory concentration; a measure of the effectiveness of a compound in inhibiting biological or biochemical function.

I.C.V. (intra-cerebroventricular) Injection of chemical into the right lateral ventricle of the brain.

Iceterus Jaundice, yellowish pigmentation of the skin.

Ichthyotoxic A substance which is poisonous to fish.

Icteric hepatitis An infectious syndrome of hepatitis characterised by jaundice, nausea, fever, right-upper-quadrant pain, enlarged liver and transaminitis (increase in alanine aminotransferase (ALT) and/or aspartate aminotransferase (AST)).

Icterus neonatorum Jaundice in newborn infants.

Idiopathic Of no apparent physical cause.

Idiopathic mesenteric phlebosclerosis (IMP) A rare disease, characterised by thickening of the wall of the right hemicolon with calcification of mesenteric veins.

Idiopathic sudden sensorineural hearing loss (ISSHL) Is sudden hearing loss where clinical assessment fails to reveal a cause.

I.g. Gastric intubation, insertion of Levin tube through the nasal passage to the stomach.

IgE Immunoglobin E – a class of antibody that plays a role in allergy.

IGFs Insulin-like growth factors, polypeptides with high sequence similarity to insulin.

IgG Immunoglobin G – the most abundant immunoglobin (antibody) and one of the major activators of the complement pathway.

IgM Immunoglobin M – primary antibody against A and B antigens on red blood cells.

IKAP Is a scaffold protein of the IvarKappaBeta kinase complex and a regulator for kinases involved in pro-inflammatory cytokine signalling.

IKappa B Or IkB-beta, a protein of the NF-Kappa-B inhibitor family.

Ileus A temporary disruption of intestinal peristalsis due to non-mechanical causes.

Immune modulator A substance that affects or modulates the functioning of the immune system.

Immunodeficiency A state in which the immune system's ability to fight infectious disease is compromised or entirely absent.

Immunogenicity The property enabling a substance to provoke an immune response, *adj*. immunogenic.

Immunoglobulin class switching, Ig class switching A biological mechanism that changes a B cell's production of antibody from one class to another.

Immunomodulatory Capable of modifying or regulating one or more immune functions.

Immunoreactive Reacting to particular antigens or haptens.

Immunostimulant Agent that stimulates an immune response.

Immunosuppression Involves a process that reduces the activation or efficacy of the immune system.

Immunotoxin A man-made protein that consists of a targeting portion linked to a toxin.

Impaired glucose tolerance (IGT) A pre-diabetic state of dysglycaemia associated with insulin resistance, increased risk of cardiovascular pathology and also a risk factor for mortality.

Impetigo A contagious bacterial skin infection characterised by blisters that may itch, caused by a *Streptoccocus* bacterium or *Staphylococcus aureus* and mostly seen in children.

Impotence A sexual dysfunction characterised by the inability to develop or maintain an erection of the penis.

Incontinence (fecal) The inability to control bowel movement.

Incontinence (urine) The inability to control urine excretion.

Incretin A group of gastrointestinal hormones that cause an increase in the amount of insulin released from beta cells of the islets of Langerhans after a meal; members include GIP and GLP-1.

Index of structural atypia (ISA) Index of structural abnormality.

Induration Hardened, as a soft tissue that becomes extremely firm, sclerosis.

Infarct An area of living tissue that undergoes necrosis as a result of obstruction of local blood supply.

Infarction Is the process of tissue death (necrosis) caused by blockage of the tissue's blood supply.

Inflammasomes Are large intracellular caspase-1activating multiprotein complexes that play a central role in innate immunity.

Inflammation A protective response of the body to infection, irritation or other injury, aimed at destroying or isolating injuries and characterised by redness, pain, warmth and swelling.

Influenza A viral infection that affects mainly the nose, throat, bronchi and, occasionally, lungs.

Infusion A liquid extract obtained by steeping something (e.g. herbs) that are more volatile or dissolve readily in water to release their active ingredients without boiling.

Inguinal hernia A hernia into the inguinal canal of the groin.

Inhalant A medicinal substance that is administered as a vapour into the upper respiratory passages.

iNOS, inducible nitric oxide synthases Through its product, nitric oxide (NO), may contribute to the induction of germ cell apoptosis. It plays a crucial role in early sepsis-related microcirculatory dysfunction.

Inotropic Affecting the force of muscle contraction.

Insecticide An agent that destroys insects. *adj*. insecticidal.

Insomnia A sleeping disorder characterised by the inability to fall asleep and/or the inability to remain asleep for a reasonable amount of time.

Insulin A peptide hormone composed of 51 amino acids produced in the islets of Langerhans in the pancreas, causes cells in the liver, muscle and fat tissue to take up glucose from the blood, storing it as glycogen in the liver and muscles. Insulin deficiency is often the cause of diabetes, and exogenous insulin is used to control diabetes.

Insulin homeostasis Blood sugar regulation.

Insulin-likegrowthfactors(IGFs) Polypeptides with high sequence similarity to insulin. They are part of a complex system that cells employ to communicate with their physiological environment.

Insulin-mimetic To act like insulin.

Insulin resistance A condtion where the natural hormone insulin becomes less effective at reducing blood sugars.

Insulinogenic Associated with or stimulating the production of insulin.

Insulinotropic Stimulating or affecting the production and activity of insulin.

Integrase An enzyme produced by a retrovirus (such as HIV) that enables its genetic material to be integrated into the DNA of the infected cell.

Interferons (IFNs) Are natural cell-signalling glycoproteins known as cytokines produced by the cells of the immune system of most vertebrates in response to challenges such as viruses, parasites and tumour cells.

Interleukins A group of naturally occurring proteins and a subset of a larger group of cellular messenger molecules called cytokines, which are modulators of cellular behaviour.

Interleukin-1 (IL-1) A cytokine that could induce fever, control lymphocytes, increase the number of bone marrow cells and cause degeneration of bone joints. Also called endogenous pyrogen, lymphocyte activating factor, haemopoetin-1 and mononuclear cell factor, amongst others IL-1 is composed of two distinct proteins, now called IL-1α and IL-1β.

Interleukin 1 beta (IL-1β) A cytokine protein produced by activated macrophages, cytokine is an important mediator of the inflammatory response and is involved in a variety of cellular activities including cell proliferation, differentiation and apoptosis.

Interleukin 2 (IL-2) A type of cytokine immune system signalling molecule that is instrumental in the body's natural response to microbial infection.

Interleukin-2 receptor (IL-2R) A heterotrimeric protein expressed on the surface of certain immune cells such as lymphocytes that binds and responds to a cytokine called IL-2.

Interleukin-6 (IL-6) An interleukin that acts as both a pro-inflammatory and anti-inflammatory cytokine.

Interleukin 8 (I- 8) A cytokine produced by macrophages and other cell types such as epithelial cells and is one of the major mediators of the inflammatory response.

Intermediate-density lipoproteins (IDL) Is one of the five major groups of lipoproteins (chylomicrons, VLDL, IDL, LDL and HDL) that enable fats and cholesterol to move within the water-based solution of the bloodstream. IDL is further degraded to form LDL particles and, like LDL, can also promote the growth of atheroma and increase cardiovascular diseases.

Intermittent claudication An aching, crampy, tired and sometimes burning pain in the legs that comes and goes, caused by peripheral vascular disease. It usually occurs with walking and disappears after rest.

Interoceptive Relating to stimuli arising from within the body.

Interstitium The space between cells in a tissue.

Interstitial Pertaining to the interstitium.

Intertrigo An inflammation (rash) caused by microbial infection in skin folds.

Intima Innermost layer of an artery or vein.

Intimal hyperplasia The thickening of the tunica intima of a blood vessel as a complication of a reconstruction procedure.

Intoxicant Substance that produces drunkenness or intoxication.

Intracavernosal Within the copus cavernsum, columns of erectile tissues forming the body of the penis.

Intraperitoneal (i.p.) The term used when a chemical is contained within or administered through the peritoneum (the thin, transparent membrane that lines the walls of the abdomen).

Intrathecal (i.t.) Through the theca of the spinal cord into the subarachnoid space.

Intromission The act of putting one thing into another.

Intubation Refers to the placement of a tube into an external or internal orifice of the body.

Iodine (I) Is an essential chemical element that is important for hormone development in the human body. Lack of iodine can lead to an enlarged thyroid gland (goitre) or other iodine deficiency disorders including mental retardation and stunted growth in babies and children. Iodine is found in dairy products, seafood, kelp, seaweeds, eggs, some vegetables and iodised salt.

IP See intraperitoneal.

IP3R3 (Inositol 1,4,5-triphosphate receptor type 3) is an intracellular calcium release channel that mediates calcium release from the endoplasmic reticulum.

Iron (Fe) Is essential to most life forms and to normal human physiology. In humans, iron is an essential component of proteins involved in oxygen transport and for haemoglobin. It is also essential for the regulation of cell growth and differentiation. A deficiency of iron limits oxygen delivery to cells, resulting in fatigue, poor work performance and decreased immunity. Conversely, excess amounts of iron can result in toxicity and even death. Dietary sources include certain cereals, dark green leafy vegetables, dried fruit, legumes, seafood, poultry and meat.

Ischaemia An insufficient supply of blood to an organ, usually due to a blocked artery.

Ischuria Retention or suppression of urine.

Isoflavones A sub-group of flavonoids in which the basic structure is a 3-phenyl chromane skeleton. They act as phytoestrogens in mammals. See flavonoids.

Isomers Substances that are composed of the same elements in the same proportions and hence have the same molecular formula but differ in properties because of differences in the arrangement of atoms.

Isoprostanes Unique prostaglandin-like compounds generated in-vivo from the free radical–catalysed peroxidation of essential fatty acids.

Jamu Traditional Indonesian herbal medicine.

Janus kinase (JAK)-signal transducer and activator of transcription (STAT) signalling Are essential molecules in cytokine signal transduction pathways involved in cancer development and progression.

Jaundice Refers to the yellow colour of the skin and whites of the eyes caused by excess bilirubin in the blood.

JNK (Jun N-terminal kinase), also known as stress-activated protein kinase (SAPK), belongs to the family of MAP kinases.

Jurkat cells A line of T lymphocyte cells that are used to study acute T-cell leukaemia.

KB cell A cell line derived from a human carcinoma of the nasopharynx, used as an assay for anti-neoplastic (anti-tumour) agents.

Kainate receptors Or KARs, are non-NMDA (N-methyl-d-aspartate) ionotropic receptors which respond to the neurotransmitter glutamate.

Kaliuresis The presence of excess potassium in the urine.

Kallikreins Peptidases (enzymes that cleave peptide bonds in proteins), a subgroup of the serine protease family; they liberate kinins from kininogens. Kallikreins are targets of active investigation by drug researchers as possible biomarkers for cancer.

Kaposi sarcoma A cancerous tumour of the connective tissues caused by the huma herpesvirus 8 and often associated with AIDS.

Kaposi sarcoma herpes virus (KSHV) Also known as human herpesvirus-8, is a gamma 2 herpesvirus or rhadinovirus. It plays an important role in the pathogenesis of Kaposi sarcoma (KS), multicentric Castleman disease (MCD) of the plasma cell type and primary effusion lymphoma and occurs in HIV patients.

Karyolysis Dissolution and disintegration of the nucleus when a cell dies.

Karyorrhexis Destructive fragmentation of the nucleus of a dying cell whereby its chromatin disintegrates into formless granules.

Keloids Benign dermal tumours characterised by fibroblastic proliferation and excessive accumulation of collagen.

Keratin A sulphur-containing protein which is a major component in skin, hair, nails, hooves, horns and teeth.

Keratinocyte Is the major constituent of the epidermis, constituting 95 % of the cells found there.

Keratinophilic Having an affinity for keratin.

Keratitis Inflammation of the cornea.

Keratoconjunctivitis sicca Also called keratitis sicca, xerophthalmia or dry eye syndrome (DES), is an eye disease characterised by a deficiency of aqueous tear film over the surface of the eye and in the lining of the lids.

Keratolysis Softening and separation of the horny layer of the epidermis.

Keratolytic Pertaining to keratolysis.

Keratomalacia An eye disorder that leads to a dry cornea.

Kidney stones Calculi, are hardened mineral deposits that form in the kidney.

Kinin Is any of various structurally related polypeptides, such as bradykinin, that act locally to induce vasodilation and contraction of smooth muscle.

Kininogen Either of two plasma α2-globulins that are kinin precursors.

Ki-67 Human protein associated with cell proliferation.

Knockout Gene knockout is a genetic technique in which an organism is engineered to carry genes that have been made inoperative.

Kunitz protease inhibitors A type of protein contained in legume seeds which functions as a protease inhibitor.

Kupffer cells Are resident macrophages of the liver and play an important role in its normal physiology and homeostasis as well as participating in the acute and chronic responses of the liver to toxic compounds.

L-Dopa (L-3,4-dihydroxyphenylalanine) is an amino acid that is formed in the liver and converted into dopamine in the brain.

Labour Process of childbirth involving muscular contractions.

Lacrimation Secretion and discharge of tears.

Lactagogue An agent that increases or stimulates milk flow or production. Also called a galactagogue.

Lactate dehydrogenase (LDH) Enzyme that catalyses the conversion of lactate to pyruvate.

Lactation Secretion and production of milk.

Lactic acidosis Is a condition caused by the build-up of lactic acid in the body. It leads to acidification of the blood (acidosis) and is considered a distinct form of metabolic acidosis.

LAK cell A lymphokine-activated killer cell, i.e. a white blood cell that has been stimulated to kill tumour cells.

Lamella In cell biology, refers to numerous plate or disc-like structures at both a tissue and a cellular level.

Laminin A glycoprotein component of connective tissue basement membrane that promotes cell adhesion.

Laparotomy A surgical procedure involving an incision through the abdominal wall to gain access into the abdominal cavity. *adj.* laparotomised.

Larvacidal An agent which kills insect or parasite larva.

Laryngitis Is an inflammation of the larynx.

Laxation Bowel movement.

Laxatives Substances that are used to promote bowel movement.

LC 50 Median lethal concentration, see LD 50.

LD 50 Median lethal dose – the dose required to kill half the members of a tested population. Also called LC 50 (median lethal concentration).

LDL See low-density lipoprotein.

LDL Cholesterol See low-density lipoprotein.

LDL receptor (LDLr) A low-density lipoprotein receptor gene.

Lectins Are sugar-binding proteins that are highly specific for their sugar moieties, that agglutinate cells and/or precipitate glycoconjugates. They play a role in biological recognition phenomena involving cells and proteins.

Leishmaniasis A disease caused by protozoan parasites that belong to the genus *Leishmania* and transmitted by the bite of certain species of sand fly.

Lenitive Palliative; easing pain or discomfort.

Lenticular opacity Also known as or related to cataract.

Leprosy A chronic bacterial disease of the skin and nerves in the hands and feet and, in some cases, the lining of the nose. It is caused by the *Mycobacterium leprae*. Also called Hansen's disease.

Leptin Is a 16 kDa protein hormone with important effects in regulating body weight, metabolism and reproductive function.

Lequesne algofunctional index Is a widespread international instrument (10-question survey) and recommended by the World Health Organisation (WHO) for outcome measurement in hip and knee diseases such as osteoarthritis.

Leucocyte White blood corpuscles, colourless, without haemoglobin, that help to combat infection.

Leucoderma A skin abnormality characterised by white spots, bands and patches on the skin; they can also be caused by fungus and tinea. Also see vitiligo.

Leucorrhoea Commonly known as whites, refers to a whitish discharge from the female genitals.

Leukaemia A cancer of the blood or bone marrow and characterised by an abnormal proliferation (production by multiplication) of blood cells, usually white blood cells (leukocytes).

Leukemogenic Relating to leukaemia, causing leukaemia.

Leukocytopenia Abnormal decrease in the number of leukocytes (white blood cells) in the blood.

Leukocytosis Increase in white blood cell count above its normal range.

Leukomyelopathy Any diseases involving the white matter of the spinal cord.

Leukopenia A decrease in the number of circulating white blood cells.

Leukoplakia Condition characterised by white spots or patches on mucous membranes, especially of the mouth and vulva.

Leukotriene A group of hormones that cause the inflammatory symptoms of hay-fever and asthma.

Leydig cells Also called interstitial cells of Leydig, are found adjacent to the seminiferous tubules in the testicle. They produce testosterone in response to luteinising hormone.

Levarterenol See Norepinephrine.

LexA repressor Or repressor LexA, is a repressor enzyme that represses SOS response genes coding for DNA polymerases required for repairing DNA damage.

Libido Sexual urge.

Lichen planus A chronic mucocutaneous disease that affects the skin, tongue and oral mucosa.

Ligroin A volatile, inflammable fraction of petroleum, obtained by distillation and used as a solvent.

Limbic system Complex set of brain structures, including the hypothalamus, amygdala, hippocampus, anterior thalamic nuclei, septum, limbic cortex and fornix that control various functions such as emotion, behaviour, motivation, memory and olfaction.

Liniment Liquid preparation rubbed on skin, used to relieve muscular aches and pains.

Linterised starch Starch that has undergone prolonged acid treatment.

Lipodiatic Having lipid- and lipoprotein-lowering property.

Lipodystrophy A medical condition characterised by abnormal or degenerative conditions of the body's adipose tissue.

Lipogenesis Is the process by which acetyl-CoA is converted to fats; adj. lipogenic.

Lipolysis Is the breakdown of fat stored in fat cells in the body.

Liposomes Artificially prepared vesicles made of lipid bilayer.

Lipotoxicity Refers to tissue diseases that may occur when fatty acids spill over in excess of the oxidative needs of those tissues and enhances metabolic flux into harmful pathways of non-oxidative metabolism.

Lipotropic Refers to compounds that help catalyse the breakdown of fat during metabolism in the body. e.g. chlorine and lecithin.

Lipoxygenase A family of iron-containing enzymes that catalyse the dioxygenation of polyunsaturated fatty acids in lipids containing a cis,cis-1,4- pentadiene structure.

Lithiasis Formation of urinary calculi (stones) in the renal system (kidneys, ureters, urinary bladder, urethra), can be of any one of several compositions.

Lithogenic Promoting the formation of calculi (stones).

Lithontripic Removes stones from kidney and gall bladder.

Liver X receptors Nuclear hormones that function as central transcriptional regulators for lipid homeostasis.

Lochia Vaginal discharge containing blood, mucus and uterine tissues during the postpartum period.

Lotion A liquid suspension or dispersion of chemicals for external application to the body.

Lovo cells Colon cancer cells.

Low-density lipoprotein (LDL) Is a type of lipoprotein that transports cholesterol and triglycerides from the liver to peripheral tissues. High levels of LDL cholesterol can signal medical problems like cardiovascular disease, and it is sometimes called 'bad cholesterol'.

LRP1 Low-density lipoprotein receptor–related protein-1, plays a role in intracellular signalling functions as well as in lipid metabolism.

LTB4 A type of leukotriene, a major metabolite in neutrophil polymorphonuclear leukocytes. It stimulates polymorphonuclear cell function (degranulation, formation of oxygen-centred free radicals, arachidonic acid release and metabolism). It induces skin inflammation.

Luciferase Is a generic name for enzymes commonly used in nature for bioluminescence.

Lumbago Is the term used to describe general lower-back pain.

Lung abscess Necrosis of the pulmonary tissue and formation of cavities containing necrotic debris or fluid caused by microbial infections.

Lusitropic An agent that affects diastolic relaxation.

Lutein A carotenoid, occurs naturally as yellow or orange pigment in some fruit and leafy vegetables. It is one of the two carotenoids contained within the retina of the eye. Within the central macula, zeaxanthin predominates, whereas in the peripheral retina, lutein predominates. Lutein is necessary for good vision and may also help prevent or slow down atherosclerosis, the thickening of arteries, which is a major risk for cardiovascular disease.

Luteinising hormone (LH) A hormone produced by the anterior pituitary gland. In females, it triggers ovulation. In males, it stimulates the production of testosterone to aid sperm maturation.

Luteolysis Is the structural and functional degradation of the corpus luteum (CL) that occurs at the end of the luteal phase of both the oestrous and menstrual cycles in the absence of pregnancy. *adj*. luteolytic.

Luteotorpic Stimulating the formation of the corpus luteum.

Lymphadenitis The inflammation or enlargement of a lymph node caused by microbial infection.

Lymphadenitis-cervical Inflammation of the lymph nodes in the neck, usually caused by an infection.

Lymphatitis Inflammation of lymph vessels and nodes.

Lymphadenopathy A term meaning 'disease of the lymph nodes' – lymph node enlargement.

Lymphadenomegaly Is the enlargement of the lymph node/nodes.

Lymphangitis An inflammation or bacterial infection of lymphatic channels, mostly commonly caused by the bacterium *Streptoccocus pyogenes* in humans.

Lymphoblastic Pertaining to the production of lymphocytes.

Lymphocyte A small white blood cell (leucocyte) that plays a large role in defending the body against disease. Lymphocytes are responsible for immune responses. There are two main types of lymphocytes: B cells and T cells. Lymphocytes secrete products (lymphokines) that modulate the functional activities of many other types of cells and are often present at sites of chronic inflammation.

Lymphocyte B cells B cells make antibodies that attack bacteria and toxins.

Lymphocyte T cells T cells attack body cells themselves when they have been taken over by viruses or have become cancerous.

Lymphoma A type of cancer involving cells of the immune system called lymphocytes.

Lymphopenia Abnormally low number of lymphocytes in the blood.

Lysosomes Are small, spherical organelles containing digestive enzymes (acid hydrolases) and other proteases (cathepsins).

mTOR, the mammalian (or mechanistic) target of rapamycin Regulates a wide range of cellular and developmental processes by coordinating signalling responses to mitogens, nutrients and various stresses.

Maceration Softening or separating of parts by soaking in a liquid.

Macrophage A type of large leukocyte that travels in the blood but can leave the bloodstream and enter tissue; like other leukocytes, it protects the body by digesting debris and foreign cells.

Macular degeneration A disease that gradually destroys the macula, the central portion of the retina, reducing central vision.

Macules Small circumscribed changes in the colour of skin that are neither raised (elevated) nor depressed.

Maculopapular Describes a rash characterised by raised, spotted lesions.

Magnesium (Mg) Is the fourth most abundant mineral in the body and is essential to good health. It is important for normal muscle and

nerve function, steady heart rhythm, immune system and strong bones. Magnesium also helps regulate blood sugar levels, promotes normal blood pressure and is known to be involved in energy metabolism and protein synthesis and plays a role in preventing and managing disorders such as hypertension, cardiovascular disease and diabetes. Dietary sources include legumes (e.g. soya bean and by-products), nuts, whole unrefined grains, fruit (e.g. banana, apricots), okra and green leafy vegetables.

MAK cell Macrophage-activated killer cell, activated nacrophage that is much more phagocytic than monocytes.

Malaise A feeling of weakness, lethargy or discomfort as of impending illness.

Malaria Is an infection of the blood by *Plasmodium* parasite that is carried from person to person by mosquitoes. There are four species of malaria parasites that infect man: *Plasmodium falciparum*, so-called 'malignant tertian fever', is the most serious disease, *Plasmodium vivax*, causing a relapsing form of the disease, *Plasmodium malariae*, and *Plasmodium ovale*.

Malassezia A fungal genus (previously known as *Pityrosporum*) classified as yeasts, naturally found on skin surfaces of many animals including humans. It can cause hypopigmentation on the chest or back if it becomes an opportunistic infection.

Mammalian target of rapamycin (mTOR) Pathway that regulates mitochondrial oxygen consumption and oxidative capacity.

Mammogram An x-ray of the breast to detect tumours.

Mandibular Relating to the mandible, the human jaw bone.

Manganese Is an essential element for heath. It is an important constituent of some enzymes and an activator of other enzymes in physiological processes. Manganese superoxide dismutase (MnSOD) is the principal antioxidant enzyme in the mitochondria. Manganese-activated enzymes play important roles in the metabolism of carbohydrates, amino acids and cholesterol. Manganese is the preferred cofactor of enzymes called glycosyltransferases, which are required for the synthesis of proteoglycans that are needed for the formation of healthy cartilage and bone. Dietary sources include whole grains, fruit, legumes (soybean and by-products), green leafy vegetables, beetroot and tea.

MAO activity Monoamine oxidase activity.

MAPK (mitogen-activated protein kinase) These kinases are strongly activated in cells subjected to osmotic stress, UV radiation, disregulated K^+ currents, RNA-damaging agents and a multitude of other stresses as well as inflammatory cytokines, endotoxin and withdrawal of a trophic factor . The stress-responsive MAPKs mediate a plethora of cellular responses to such stressful stimuli, including apoptosis and production of inflammatory and immunoregulatory cytokines in diverse cell systems.

Marasmus Is one of the three forms of serious protein energy malnutrition.

Mastectomy Surgery to remove a breast.

Masticatory A substance chewed to increase salivation. Also called sialogue.

Mastitis A bacterial infection of the breast which usually occurs in breastfeeding mothers.

Matrix metalloproteinases (MMP) A member of a group of enzymes that can break down proteins, such as collagen, that are normally found in spaces between cells in tissues (i.e. extracellular matrix proteins). Matrix metalloproteinases are involved in wound healing, angiogenesis and tumour cell metastasis. See also metalloproteinase.

MBC Minimum bacterial concentration – the lowest concentration of antibiotic required to kill an organism.

MCP-1 Monocyte chemotactic protein-1, plays a role in the recruitment of monocytes to sites of infection and injury. It is a member of small inducible gene (SIG) family.

MDA Malondialdehyde is one of the most frequently used indicators of lipid peroxidation.

Measles An acute, highly communicable rash illness due to a virus transmitted by direct contact with infectious droplets or, less commonly, by airborne spread.

Mechanonociceptors Sensory neurons that are mechanically sensitive, found in all the paraspinal connective tissues including ligament, joint capsule, annulus fibrosus of the intervertebral disk, muscle, tendon and skin. They respond to a noxious (damaging) mechanical load.

Medial preoptic area Is located at the rostral end of the hypothalamus, it is important for the regulation of male sexual behaviour.

Megaloblastic anaemia An anaemia that results from inhibition of DNA synthesis in red blood cell production, often due to a deficiency of vitamin B12 or folate and characterised by many large immature and dysfunctional red blood cells (megaloblasts) in bone marrow.

Melaene (melena) Refers to the black, 'tarry' feces that are associated with gastrointestinal haemorrhage.

Melanogenesis Production of melanin by living cells.

Melanoma Malignant tumour of melanocytes which are found predominantly in skin but also in the bowel and the eye and appear as pigmented lesions.

Melatonin A hormone produced in the brain by the pineal gland, it is important in the regulation of the circadian rhythms of several biological functions.

Menarche The first menstrual cycle, or first menstrual bleeding, in female human beings.

Menorrhagia Heavy or prolonged menstruation, too frequent menstrual periods.

Menopausal Refers to permanent cessation of menstruation.

Menses See menstruation.

Menstruation The approximately monthly discharge of blood from the womb in women of childbearing age who are not pregnant. Also called menses. *adj*. menstrual.

Mesangial cells Are specialised cells around blood vessels in the kidneys, at the mesangium.

Mesothelioma Is an aggressive cancer affecting the membrane lining of the lungs and abdomen.

Metabolic syndrome (MetS) Represents a combination of cardiometabolic risk factors, including visceral obesity, glucose intolerance or type 2 diabetes, elevated triglycerides, reduced HDL cholesterol and hypertension.

Metabonome Complete set of metabologically regulated elements in cells.

Metabolomics Is the scientific study of chemical processes involving metabolites.

Metalloproteinase Enzymes that break down proteins requiring zinc or calcium atoms for proper function.

Metallothionein (MT) A family of cysteine-rich, low–molecular weight (500–14,000 Da) proteins.

Meta-analysis A statistical procedure that combines the results of several studies that address a set of related research hypotheses.

Metaphysis Is the portion of a long bone between the epiphyses and the diaphysis of the femur.

Metaphyseal Pertaining to the metaphysis.

Metaplasia Transformation of one mature differentiated cell type into another mature differentiated cell type.

Metastasis Is the movement or spreading of cancer cells from one organ or tissue to another.

Metetrus The quiescent period of sexual inactivity between oestrus cycles.

Methemoglobinemia Is a disorder characterised by the presence of a higher-than-normal level of methemoglobin (ferric [$Fe3^{+}$] rather than ferrous [$Fe2^{+}$] haemoglobin) in red blood cells. This results in a decreased availability of oxygen to tissues.

Metropathy Any disease of the uterus, especially of the myometrium.

Metroptosis The slipping or falling out of place of an organ (as the uterus).

Metrorrhagia Uterine bleeding at irregular intervals, particularly between the expected menstrual periods.

Mevinolin A potent inhibitor of 3-hydroxy-3-methylglutaryl coenzyme A reductase (HMG-CoA reductase).

MHC Acronym for major histocompatibility complex, a large cluster of genes found on the short arm of chromosome 6 in most vertebrates that encodes MHC molecules. MHC molecules play an important role in the immune system and autoimmunity.

MHC 11 molecules Class II MHC molecules belong to a group of molecules known as the immunoglobulin supergene family, which includes immunoglobulins, T-cell receptors, CD4, CD8 and others.

MIC Minimum inhibitory concentration – lowest concentration of an antimicrobial that will inhibit the visible growth of a microorganism.

Micelle A submicroscopic aggregation of molecules.

Micellisation Formation process of micelles.

Microangiopathy Or microvascular disease, is an angiopathy affecting small blood vessels in the body.

Microfilaria A pre-larval parasitic worm of the family *Onchocercidae*, found in the vector and in the blood or tissue fluid of human hosts.

Micronuclei Small particles consisting of acentric fragments of chromosomes or entire chromosomes, which lag behind at anaphase of cell division.

Microphthalmia-associated transcription factor (MITF) A basic helix-loop-helix leucine zipper transcription factor protein that plays a role in the development, survival and function of melanocytes and osteoclast.

Microsomal PGE2 synthase Is the enzyme that catalyses the final step in prostaglandin E2 (PGE2) biosynthesis.

Microvasculature The finer vessels of the body, as the arterioles, capillaries and venules.

Micturition Urination, act of urinating.

Migraine A neurological syndrome characterised by altered bodily perceptions, severe painful headaches and nausea.

Mimosine Is an alkaloid, β-3-hydroxy-4 pyridone amino acid, it is a toxic non-protein free amino acid and is an antinutrient.

Mineral apposition rate MAR, rate of addition of new layers of mineral on the trabecular surfaces of bones.

Miscarriage Spontaneous abortion.

Mitochondrial complex I The largest enzyme in the mitochondrial respiratory oxidative phosphorylation system.

Mitochondrial permeability transition (MPT) Is an increase in the permeability of the mitochondrial membranes to molecules of less than 1,500 Da in molecular weight. MPT is one of the major causes of cell death in a variety of conditions.

Mitogen An agent that triggers mitosis, elicits all the signals necessary to induce cell proliferation.

Mitogenic Able to induce mitosis or transformation.

Mitogenicity Process of induction of mitosis.

Mitomycin A chemotherapy drug that is given as a treatment for several different types of cancer, including breast, stomach, oesophagus and bladder cancers.

Mitosis Cell division in which the nucleus divides into nuclei containing the same number of chromosomes.

MMP Matrix metalloproteinases, a group of peptidases involved in degradation of the extracellular matrix (ECM).

Mnestic Pertaining to memory.

Molecular docking Is a key tool in structural molecular biology and computer-assisted drug design.

Molluscidal Destroying molluscs like snails.

Molt 4 cells MOLT4 cells are lymphoblast-like in morphology and are used for studies of apoptosis, tumour cytotoxicity, tumorigenicity as well as for anti-tumour testing.

Molybdenum (Mo) Is an essential element that forms part of several enzymes such as xanthine oxidase involved in the oxidation of xanthine to uric acid and use of iron. Molybdenum concentrations also affect protein synthesis, metabolism and growth. Dietary sources include meat, green beans, eggs, sunflower seeds, wheat flour, lentils and cereal grain.

Monoamine oxidase A (MAOA) Is an isozyme of monoamine oxidase. It preferentially deaminates norepinephrine (noradrenaline), epinephrine (adrenaline), serotonin and dopamine.

Monoaminergic Of or pertaining to neurons that secrete monoamine neurotransmitters (e.g., dopamine, serotonin).

Monoclonal antibodies Are produced by fusing single antibody-forming cells to tumour cells grown in culture.

Monocyte Large white blood cell that ingests microbes, other cells and foreign matter.

Monogalactosyl diglyceride Are the major lipid components of chloroplasts.

Monorrhagia Is heavy bleeding that is usually defined as periods lasting longer than 7 days or excessive bleeding.

Morbidity A diseased state or symptom, or can refer either to the incidence rate or to the prevalence rate of a disease.

Morelloflavone A biflavonoid extracted from *Garcinia dulcis*, has shown antioxidative, antiviral and anti-inflammatory properties.

Morphine The major alkaloid of opium and a potent narcotic analgesic.

MTTP Microsomal triglyceride transfer protein that is required for the assembly and secretion of triglyceride-rich lipoproteins from both enterocytes and hepatocytes.

MUC 5AC Mucin 5AC, a secreted gel-forming protein mucin with a high molecular weight of about 641 kDa.

Mucositis Painful inflammation and ulceration of the mucous membranes lining the digestive tract.

Mucous Relating to mucus.

Mucolytic Capable of reducing the viscosity of mucus or an agent that so acts.

Mucus Viscid secretion of the mucous membrane.

Multidrug resistance (MDR) Ability of a living cell to show resistance to a wide variety of structurally and functionally unrelated compounds.

Muscarinic receptors Are G protein-coupled acetylcholine receptors found in the plasma membranes of certain neurons and other cells.

Musculotropic Affecting or acting upon muscular tissue.

Mutagen An agent that induces genetic mutation by causing changes in the DNA.

Mutagenic Capable of inducing mutation (used mainly for extracellular factors such as X-rays or chemical pollution).

Myalgia Muscle pain.

Myc Codes for a protein that binds to the DNA of other genes and is therefore a transcription facor, found on chromosome 8 in humans.

Mycosis An infection or disease caused by a fungus.

Mydriasis Abnormal, excessive dilation of the pupil caused by disease or drug.

Myelocyte Is a young cell of the granulocytic series, occurring normally in bone marrow but not in circulating blood.

Myeloid leukaemia (chronic) A type of cancer that affects the blood and bone marrow, characterised by excessive number of white blood cells.

Myeloma Cancer that arises in the plasma cells, a type of white blood cells.

Myeloperoxidase (MPO) Is a peroxidase enzyme most abundantly present in neutrophil granulocytes (a sub-type of white blood cells). It is an inflammatory enzyme produced by activated leukocytes that predicts risk of coronary heart disease.

Myeloproliferative disorder Disease of the bone marrow in which excess cells are produced.

Myelosuppressive Causing bone marrow suppression.

Myelotoxicity State of being toxic to myeloid tissues, the bone marrow.

Myiasis Parasitic infestation of the body of a live mammal by fly larvae.

Myocardial Relating to heart muscle tissues.

Myocardial infarction (MI) Is the rapid development of myocardial necrosis caused by a critical imbalance between oxygen supply and demand of the myocardium.

Myocardial ischaemia An intermediate condition in coronary artery disease during which the heart tissue is slowly or suddenly starved of oxygen and other nutrients.

Myocardial lipidosis Is the accumulation of fat droplets in myocardial fibres.

Myoclonus Brief, involuntary twitching of a muscle or a group of muscles.

Myogenesis The formation of musculer tissue, especially during embryonic development.

Myopathy A muscular disease wherein the muscle fibres do not function for any one of many reasons, resulting in muscular weakness.

Myopia Near – or short-sightedness.

Myosarcoma A malignant muscle tumour.

Myotonia dystrophica An inherited disorder of the muscles and other body systems characterised by progressive muscle weakness, prolonged muscle contractions (myotonia), clouding of the lens of the eye (cataracts), cardiac abnormalities, balding and infertility.

Myotube A developing skeletal muscle fibre or cell with a tubular appearance and a centrally located nucleus.

Myringosclerosis Also known as tympanosclerosis or intratympanic tympanosclerosis, is a

condition caused by calcification of collagen tissues in the tympanic membrane of the middle ear.

Mytonia A symptom of certain neuromuscular disorders characterised by the slow relaxation of the muscles after voluntary contraction or electrical stimulation.

N-nitrosmorpholine A human carcinogen.

N-nitrosoproline An indicator for N-nitrosation of amines.

Nicotinamide adenine dinucleotide phosphate (NADP) A coenzyme comprising nicotinamide mononucleotide coupled by pyrophosphate linkage to adenosine 2′,5′-bisphosphate; it acts as an electron carrier in numerous reactions, being alternately oxidised (NADP+) and reduced (NADPH).

NADPH The reduced form of nicotinamide adenine dinucleotide phosphate that serves as an electron carrier.

NAFLD Non-alcoholic fatty liver disease.

Narcotic An agent that produces narcosis; in moderate doses, it dulls the senses, relieves pain and induces sleep; in excessive dose, it causes stupor, coma, convulsions and death.

Nasopharynx Upper part of the alimentary continuous with the nasal passages.

Natriorexia Excessive intake of sodium evoked by sodium depletion. *adj*. natriorexic, natriorexigenic.

Natriuresis The discharge of excessive large amounts of sodium through urine. *adj*. natriuretic.

Natural killer cells (NK cells) A type of cytotoxic lymphocyte that constitute a major component of the innate immune system.

Natural killer T (NKT) cells A heterogeneous group of T cells that share properties of both T cells and natural killer (NK) cells.

Nausea Sensation of unease and discomfort in the stomach with an urge to vomit.

Necropsy See autopsy.

Necrosis Morphological changes that follow cell death, usually involving nuclear and cytoplasmic changes.

Neointima A new or thickened layer of arterial intima formed especially on a prosthesis or in atherosclerosis by migration and proliferation of cells from the media.

Neonatal *Adj*. Of or relating to newborn infants or an infant.

Neoplasia Abnormal growth of cells, which may lead to a neoplasm or tumour.

Neoplasm Tumour; any new and abnormal growth, specifically one in which cell multiplication is uncontrolled and progressive. Neoplasms may be benign or malignant.

Neoplastic transformation Conversion of a tissue with a normal growth pattern into a malignant tumour.

Neovascularisation Is the development of tiny, abnormal, leaky blood vessels inside the eye.

Neovasculature Formation of new blood vessels.

Nephrectomised Kidneys surgically removed.

Nephrectomy Surgical removal of the kidney.

Nephric Relating to or connected with a kidney.

Nephrin Is a protein necessary for the proper functioning of the renal filtration barrier.

Nephritic syndrome Is a collection of signs (known as a syndrome) associated with disorders affecting the kidneys, more specifically glomerular disorders.

Nephritis Is inflammation of the kidney.

Nephrolithiasis Process of forming a kidney stone in the kidney or lower urinary tract.

Nephropathy A disorder of the kidney.

Nephrotic syndrome Non-specific disorder in which the kidneys are damaged, causing them to leak large amounts of protein from the blood into the urine.

Nephrotoxicity Poisonous effect of some substances, both toxic chemicals and medication, on the kidney.

Nerve growth factor (NGF) A small protein that induces the differentiation and survival of particular target neurons (nerve cells).

Nervine A nerve tonic that acts therapeutically upon the nerves, particularly in the sense of a sedative that serves to calm ruffled nerves.

Neural tube defects (NTDs) Are common birth defects of the brain and spinal cord.

NEU 4 sialidase This protein belongs to a family of glycohydrolytic enzymes, which remove terminal sialic acid residues from various sialo derivatives, such as glycoproteins, glycolipids, oligosaccharides and gangliosides.

Neuralgia Is a sudden, severe painful disorder of the nerves.

Neuraminidase Glycoside hydrolase enzyme that cleaves the glycosidic linkages of neuraminic acids.

Neuraminidase inhibitors A class of antiviral drugs targeted at the influenza viruses whose mode of action consists of blocking the function of the viral neuraminidase protein, thus preventing the virus from reproducing.

Neurasthenia A condition with symptoms of fatigue, anxiety, headache, impotence and neuralgia.

Neurasthenic A substance used to treat nerve pain and/or weakness (i.e. neuralgia, sciatica, etc.).

Neurectomy Surgical cutting through or removal of a nerve or a section of a nerve.

Neurite Refers to any projection from the cell body of a neuron.

Neuritis An inflammation of the nerve characterised by pain, sensory disturbances and impairment of reflexes. *adj*. neuritic.

Neuritogenesis The formation of neuritis. a*dj*. neuritogenic.

Neuroblastoma A common extracranial cancer that forms in nerve tissues, common in infancy.

Neuroendocrine *Adj*. Of, relating to or involving the interaction between the nervous system and the hormones of the endocrine glands.

Neurogenesis Process by which neurons are generated from neural stem and progenitor cells.

Neurogenic Originating from the nerves of the nervous system.

Neurolathyrism Is a neurodegenerative disease that is caused by heavy consumption of *Lathyrus* legumes, resulting in weakness and paralysis of the legs.

Neuroleptic Refers to the effects on cognition and behaviour of antipsychotic drugs that reduce confusion, delusions, hallucinations and psychomotor agitation in patients with psychoses.

Neuroma Is a growth or tumour of nerve tissue.

Neuropathy A collection of disorders that occurs when the peripheral nervous sytems are damaged causing pain and numbness in the hands and feet.

Neuropharmacological Relating to the effects of drugs on the neurosystem.

Neuroradiology Is a subspecialty of radiology focusing on the diagnosis and characterisation of abnormalities of the central and peripheral nervous system. *adj*. neuroradiologic.

Neurotrophic Relating to the nutrition and maintenance of nervous tissue (neurons).

Neutropenia A disorder of the blood, characterised by abnormally low levels of neutrophils.

Neutrophil Type of white blood cell, specifically a form of granulocyte.

Neutrophin Protein that induces the survival, development and function of neurons.

NF-kappa B (NF-kB) Nuclear factor kappa B, is an ubiquitous rapid-response transcription factor in cells involved in immune and inflammatory reactions.

Niacin Vitamin B3. See vitamin B3.

Niacinamide An amide of niacin, also known as nicotinamide. See vitamin B3.

NIH3T3 cells A mouse embryonic fibroblast cell line used in the cultivation of keratinocytes.

Nidation Implantation.

Niosomes Are novel, vesicular drug delivery systems composed of non-ionic surfactants instead of phospholipids; they are capable of entrapping hydrophilic and hydrophobic drugs.

Nitrogen (N) Is an essential building block of amino and nucleic acids and proteins and is essential to all living organisms. Protein-rich vegetables like legumes are rich food sources of nitrogen.

NK cells Natural killer cells, a type of cytotoxic lymphocyte that constitute a major component of the innate immune system.

NK1.1+ T (NKT) cells A type of natural killer T (NKT) cells. See natural killer T cells.

NMDA receptor N-methyl-D-aspartate receptor, the predominant molecular device for controlling synaptic plasticity and memory function. A brain receptor activated by the amino acid glutamate, which, when excessively stimulated, may cause cognitive defects in Alzheimer's disease.

Nociceptive Causing pain, responding to a painful stimulus.

Nociceptors Specialised peripheral sensory neurons that respond to potentially damaging stimuli by sending nerve signals to the spinal cord and brain.

Non-osteogenic Fibromata of bone, a benign tumour of bone which shows no evidence of ossification.

Non-alcoholic fatty liver disease One cause of a fatty liver, occurring when fat is deposited (steatosis) in the liver not due to excessive alcohol use.

Nootropics Are substances which are claimed to boost human cognitive abilities (the functions and capacities of the brain). Also popularly referred to as 'smart drugs', 'smart nutrients', 'cognitive enhancers' and 'brain enhancers'.

Noradrenalin See Norepinephrine.

Norepinephrine A substance, both a hormone and neurotransmitter, secreted by the adrenal medulla and the nerve endings of the sympathetic nervous system to cause vasoconstriction and increases in heart rate, blood pressure and the sugar level of the blood. Also called levarterenol, noradrenalin.

Normoglycaemic Having the normal amount of glucose in the blood.

Normotensive Having normal blood pressure.

Nosebo A harmless substance that, when taken by a patient, is associated with unpleasant or harmful effects due to negative expectations or the psychological state of the person.

Nosocomial infections Infections which are a result of treatment in a hospital or a healthcare service unit but secondary to the patient's original condition.

NPC1L1 Niemann–Pick C1-Like 1 gene that plays a major role in cholesterol homeostasis. It is critical for the uptake of cholesterol across the plasma membrane of the intestinal enterocyte.

Nrf2 Nuclear erythroid 2-related factor 2, a transcription factor that activates ARE-containing genes.

Nrf2/ARE pathway Plays an important role in inducing phase II detoxifying enzymes and antioxidant proteins and has been considered a potential target for cancer chemoprevention because it eliminates harmful reactive oxygen species or reactive intermediates generated from carcinogens.

Nuclear factor erythroid 2-related factor 2 (Nrf2) A transcription factor that plays a major role in response to oxidative stress by binding to antioxidant-responsive elements that regulate many hepatic phase I and II enzymes as well as hepatic efflux transporters.

Nucleosomes Fundamental repeating subunits of all eukaryotic chromatin, consisting of a DNA chain coiled around a core of histones.

Nulliparous Term used to describe a woman who has never given birth.

Nyctalopia Night blindness, impaired vision in dim light and in the dark, due to impaired function of certain specialised vision cells.

Nystagmus Fast, involuntary movements of the eyes.

Nycturia Excessive urination at night; especially common in older men.

Obsessive–compulsive disorder (OCD) A common psychiatric disorder defined by the presence of obsessive thoughts and repetitive compulsive actions; self-grooming.

Occludin A novel integral membrane protein localising at tight junctions. *cf*. tight junction.

Occlusion Closure or blockage (as of a blood vessel).

Occlusive peripheral arterial disease (PAOD) Also known as peripheral vascular disease (PVD) or peripheral arterial disease (PAD), refers to the obstruction of large arteries not within the coronary, aortic arch vasculature or brain. PVD can result from atherosclerosis, inflammatory processes leading to stenosis, an embolism or thrombus formation.

Oculomotor nerve The third of twelve paired cranial nerves.

Odds ratio A statistical measure of effect size, describing the strength of association or non-independence between two binary data values.

Odontalgia Toothache. *adj*. odontalgic.

Odontopathy Any disease of the teeth.

Oedema See edema.

Oligoarthritis An inflammation of two, three or four joints.

Oligoasthenoteratozoospermia Male infertility, refers to the inability of a male to achieve a pregnancy in a fertile female.

Oligonucleosome A series of nucleosomes.

Oligospermia or oligozoospermia Refers to semen with a low concentration of sperm, commonly associated with male infertility.

Oliguria Decreased production of urine.

Oligoanuria Insufficient urine volume to allow for administration of necessary fluids, etc.

Omega 3 fatty acids Are essential polyunsaturated fatty acids that have in common a final carbon–carbon double bond in the $n-3$ position. Dietary sources of omega-3 fatty acids include fish oil and certain plant/nut oils. The three most nutritionally important omega 3 fatty acids are alpha-linolenic acid, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Research indicates that omega 3 fatty acids are important in health promotion and disease and can help prevent a wide range of medical problems, including cardiovascular disease, depression, asthma and rheumatoid arthritis.

Omega 6 fatty acids Are essential polyunsaturated fatty acids that have in common a final carbon–carbon double bond in the $n-6$ position. Omega-6 fatty acids are considered essential fatty acids (EFAs) found in vegetable oils, nuts and seeds. They are essential to human health but cannot be made in the body. Omega-6 fatty acids – found in vegetable oils, nuts and seeds – are a beneficial part of a heart-healthy eating. Omega-6 and omega-3 PUFA play a crucial role in heart and brain function and in normal growth and development. Linoleic acid (LA) is the main omega-6 fatty acid in foods, accounting for 85–90 % of the dietary omega-6 PUFA. Other omega 6 acids include gamma-linolenic acid or GLA, sometimes called gamoleic acid, eicosadienoic acid, arachidonic acid and docosadienoic acid.

Omega 9 fatty acids Are not essential polyunsaturated fatty acids that have in common a final carbon–carbon double bond in the $n-9$ position. Some $n-9$ s are common components of animal fat and vegetable oil. Two $n-9$ fatty acids important in industry are oleic acid (18:1, $n-9$), which is a main component of olive oil, and erucic acid (22:1, $n-9$), which is found in rapeseed, wallflower seed and mustard seed.

Oncogenes Genes carried by tumour viruses that are directly and solely responsible for the neoplastic (tumorous) transformation of host cells.

Oncosis Accidental cell death, also referred to swelling necrosis.

Ophthalmia Severe inflammation of eyes or the conjunctiva or deeper structures of the eye . Also called ophthalmitis.

Ophthalmia (sympathetic) Inflammation of both eyes following trauma to one eye.

Ophthalmopathy An auntoimmune disease where the thyroid gland is overactive leading to ocular manifestations.

Opiate Drug derived from the opium plant.

Opioid receptors A group of G-protein-coupled receptors located in the brain and various organs that bind opiates or opioid substances.

Oppilation Obstruction, particularly of the lower intestines.

Optic placode An ectodermal placode from which the lens of the embryonic eye develops; also called lens placode.

ORAC (oxygen radical absorbance capacity) A method of measuring antioxidant capacities in biological samples.

Oral submucous fibrosis A chronic debilitating disease of the oral cavity characterised by inflammation and progressive fibrosis of the sub-mucosa tissues.

Oral thrush An infection of yeast fungus, *Candida albicans*, in the mucous membranes of the mouth.

Orchidectomy Surgery to remove one or both testicles.

Orchidectomised With testis removed.

Orchitis An acute painful inflammatory reaction of the testis secondary to infection by different bacteria and viruses.

Orexigenic Increasing or stimulating the appetite.

Orofacial dyskinesia Abnormal involuntary movements involving muscles of the face, mouth, tongue, eyes and, occasionally, the neck – may be unilateral or bilateral and constant or intermittent.

Oropharyngeal Relating to the oropharynx.

Oropharynx Part of the pharynx between the soft palate and the epiglottis.

Osmophobia A fear, aversion or psychological hypersensitivity to odours.

Ostalgia, ostealgia Pain in the bones. Also called osteodynia.

Osteoarthritis Is the deterioration of the joints that becomes more common with age.

Osteoarthrosis Chronic non-inflammatory bone disease.

Osteoblast A mononucleate cell that is responsible for bone formation.

Osteoblastic Relating to osteoblasts.

Osteocalcin A non-collagenous protein found in bone and dentin, also referred to as bone gamma-carboxyglutamic acid–containing protein.

Osteoclasts A kind of bone cell that removes bone tissue by removing its mineralised matrix.

Osteoclastogenesis The production of osteoclasts.

Osteodynia Pain in the bone.

Osteogenic Derived from or composed of any tissue concerned in bone growth or repair.

Osteomalacia Refers to the softening of the bones due to defective bone mineralisation.

Osteomyelofibrosis A myeloproliferative disorder in which fibrosis and sclerosis finally lead to bone marrow obliteration.

Osteopenia Reduction in bone mass, usually caused by a lowered rate of formation of new bone that is insufficient to keep up with the rate of bone destruction.

Osteoporosis A disease of bone that leads to an increased risk of fracture.

Osteoprotegerin Also called osteoclastogenesis inhibitory factor (OCIF), a cytokine which can inhibit the production of osteoclasts.

Osteosarcoma A malignant bone tumour. Also called osteogenic sarcoma.

Otalgia Earache, pain in the ear.

Otic placode A thickening of the ectoderm on the outer surface of a developing embryo from which the ear develops.

Otitis Inflammation of the inner or outer parts of the ear.

Otitis media Inflammation of the middle ear.

Otorrhoea Running drainage (discharge) exiting the ear.

Otopathy Disease of the ear.

Ovariectomised With one or two ovaries removed.

Ovariectomy Surgical removal of one or both ovaries.

Oxidation The process of adding oxygen to a compound, dehydrogenation or increasing the electro-negative charge.

Oxidoreductase activity Catalysis of an oxidation–reduction (redox) reaction, a reversible chemical reaction. One substrate acts as a hydrogen or electron donor and becomes oxidised, while the other acts as hydrogen or electron acceptor and becomes reduced.

Oxygen radical absorbance capacity (ORAC) A method of measuring antioxidant capacities in biological samples.

Oxytocic *Adj*. Hastening or facilitating childbirth, especially by stimulating contractions of the uterus.

Oxytocin Is a mammalian hormone that also acts as a neurotransmitter in the brain. It is best known for its roles in female reproduction: It is released in large amounts after distension of the cervix and vagina during labour and after stimulation of the nipples, facilitating birth and breastfeeding, respectively.

Oxyuriasis Infestation by pinworms.

Ozoena Discharge of the nostrils caused by chronic inflammation of the nostrils.

p.o. Per os, oral administration.

P-glycoprotein (P-gp, ABCB1, MDR1) A cell membrane–associated drug-exporting protein that transports a variety of drug substrates from cancer cells.

P-selectin Also known as CD62P, GMP-140, LLECAM-3, PADGEM, a member of the selectin family. It is expressed by activated platelets and endothelial cells.

P65 transcription factor Is a protein that in humans is encoded by the RELA gene. Its alternative name is nuclear factor NF-kappa-B p65 sub-unit.

P300/CBP Are transcriptional co-activators that play critical roles in integrating multiple signal-dependent transcription events and may have specific roles in tumour suppression pathways.

p21waf1/cip1 Encodes a cyclin-dependent kinase inhibitor that is transcriptionally activated by the p53 tumour suppressor gene, transforming growth factor beta 1 (TGF-beta 1), AP2 and other pathways, all regulating apoptosis and the cell cycle.

Palliative Relieving pain without alleviating the underlying problem.

Palinosmia Olfactory preservation.

Palpebral ptosis The abnormal drooping of the upper lid, caused by partial or total reduction in levator muscle function.

Palpitation Rapid pulsation or throbbing of the heart.

Paludism State of having symptoms of malaria characterised by high fever and chills.

Pancreatectomised Having undergone a pancreatectomy.

Pancreatectomy Surgical removal of all or part of the pancreas.

Pancreatitis Inflammation of the pancreas.

Pancytopenia A haematological condition in which there is a reduction in the number of red and white blood cells as well as platelets.

Pantothenic acid Vitamin B5. See vitamin B5.

Papain A protein-degrading enzyme used medicinally and to tenderise meat.

Papilloma A benign epithelial tumour growing outwardly like in finger-like fronds.

Papule A small, solid, usually inflammatory elevation of the skin that does not contain pus.

Paradontosis Is the inflammation of gums and other deeper structures, including the bone.

Parageusia Abnormal sense of taste.

Paralytic Person affected with paralysis, pertaining to paralysis.

Paraoxonase An enzyme that protects against oxidation of low-density lipoprotein and affects the risk of coronary artery disease.

Paraplegia An impairment in motor or sensory function of the lower extremities.

Parasitemia Presence of parasites in blood. *adj*. parasitemic.

Parasympathetic nervous system Sub-system of the nervous system that slows the heart rate, increases intestinal and gland activity and relaxes the sphincter muscles.

Parasympathomimetic Having an action resembling that caused by stimulation of the parasympathetic nervous system.

Parenteral administration Admininistration by intravenous, subcutaneous or intramuscular routes.

Paresis A condition characterised by partial loss of movement or impaired movement.

Paresthesia A sensation of tingling, burning, pricking or numbness of a person's skin with no apparent long-term physical effect. Also known as 'pins and needles'.

Parotitis Inflammation of salivary glands.

Paroxysm A sudden outburst of emotion or action, a sudden attack, recurrence or intensification of a disease.

Paroxystic Relating to an abnormal event of the body with an abrupt onset and an equally sudden return to normal.

PARP See poly (ADP-ribose) polymerase.

Pars compacta Is a portion of the substantia nigra (a brain structure located in the midbrain).

Parturition Act of childbirth.

Pathognomonic Distinctively characteristic of a particular disease.

PCAF P300/CBP-associated factor, a histone acetyl transferase (HAT) that plays an important role in the remodelling of chromatin and the regulation of gene expression, transcription, cell cycle progression and differentiation.

PCE/PCN ratio Polychromatic erythrocyte/normochromatic erythrocyte ratio use as a measure of cytotoxic effects.

PCNA Proliferating cell nuclear antigen, an auxiliary protein of DNA polymerase delta involved in modulating eukaryotic DNA replication.

pCREB Phosphorylated cAMP (adenosine 3′5′ cyclic monophosphate)-response element binding protein.

PDEF Acronym for prostate-derived ETS factor, an ETS (epithelial-specific E26 transforming sequence) family member that has been identified as a potential tumour suppressor.

PDGR receptor (platelet-derived growth factor receptor) Are cell surface tyrosine kinase receptors for members of the platelet-derived growth factor (PDGF) family.

PDGFs Platelet-derived growth factors constitute a group of growth factors that play a significant role in blood vessel formation and the growth of blood vessels.

Pectoral Pertaining to or used for the chest and respiratory tract.

pERK Phosphorylated extracellular signal-regulated kinase, protein kinases involved in many cell functions.

P53 Also known as protein 53 or tumour protein 53, is a tumour suppressor protein that in humans is encoded by the TP53 gene.

Peliosis See purpura.

Pellagra Is a systemic nutritional wasting disease caused by a deficiency of vitamin B3 (niacin).

Pemphigus Describes a group of autoimmune disorders in which there is blistering of the skin and/or mucosal surfaces.

Pemphigus neonatorum Staphylococcal scalded skin syndrome, a bacterial disease of infants, characterised by elevated vesicles or blebs on a normal or reddened skin.

Peptic ulcer A sore in the lining of the stomach or duodenum, the first part of the small intestine.

Peptide YY A short (36 amino acid) pancreatic protein released by cells in the ileum and colon in response to feeding.

Percutanous Pertains to a medical procedure where access to inner organs or tissues is via needle puncture of the skin.

Perfusion To force fluid through the lymphatic system or blood vessels to an organ or tissue.

Periapical periodontitis Is the inflammation of the tissue adjacent to the tip of the tooth's root.

Perifuse To flush a fresh supply of bathing fluid around all of the outside surfaces of a small piece of tissue immersed in it.

Perilipins Highly phosphorylated adipocyte proteins that are localised at the surface of the lipid droplet.

Perimenopause Is the phase before menopause actually takes place, when ovarian hormone production is declining and fluctuating. *adj*. perimenopausal.

Perineum The region between the thighs inferior to the pelvic diaphragm.

Perineal Pertaining to the perineum.

Periodontal ligament (PDL) Is a group of specialised connective tissue fibres that essentially attach a tooth to the bony socket.

Periodontitis Is a severe form of gingivitis in which the inflammation of the gums extends to the supporting structures of the tooth. Also called pyorrhoea.

Perioral paresthesias Are sensations of numbness and tingling around the mouth.

Peripheral arterial disease (PAD) Is a disease in which plaque builds up in the arteries that carry blood to your head, organs and limbs.

Peripheral neuropathy Refers to damage to nerves of the peripheral nervous system.

Peripheral neuropathic pain (PNP) Refers to situations where nerve roots or peripheral nerve trunks have been damaged by mechanical and/or chemical stimuli that exceeded the physical capabilities of the nervous system. Symptoms may include pain, parestesia, dysesthesia, spasm, weakness, hypoesthesia or anesthesia.

Peripheral vascular disease (PVD) See peripheral artery occlusive disease.

Peristalsis A series of organised, wave-like muscle contractions that occur throughout the digestive tract.

PERK A trans-membrane protein kinase of the PEK family resident in the endoplasmic reticulum (ER) membrane and linked to insulin processing.

Perlingual Through or by way of the tongue.

Perniosis An abnormal reaction to cold that occurs most frequently in women, children and the elderly. Also called chilblains.

Per os (P.O.) Oral administration.

Peroxisome proliferator-activated receptors (PPARs) A family of nuclear receptors that are involved in lipid metabolism, differentiation, proliferation, cell death and inflammation.

Peroxisome proliferator-activated receptor alpha (PPAR-alpha) A nuclear receptor protein, transcription factor and a major regulator of lipid metabolism in the liver.

Peroxisome proliferator-activated receptor gamma (PPAR-γ) A type-II nuclear receptor protein that regulates fatty acid storage and glucose metabolism.

Pertussis Whooping cough, severe cough.

Peyers patches Patches of lymphoid tissue or lymphoid nodules on the walls of the ileal-small intestine.

PGE-2 Prostaglandin E2, a hormone-like substance that is released by blood vessel walls in response to infection or inflammation that acts on the brain to induce fever.

Phagocytes Are the white blood cells that protect the body by ingesting (phagocytosing)

harmful foreign particles, bacteria and dead or dying cells. *adj*. phagocytic.

Phagocytosis Is process the human body uses to destroy dead or foreign cells.

Phantosmia A form of olfactory hallucination.

Pharmacognosis The branch of pharmacology that studies the composition, use and history of drugs.

Pharmacodynamics Branch of pharmacology dealing with the effects of drugs and the mechanism of their action.

Pharmacokinetics Branch of pharmacology concerned with the movement of drugs within the body including processes of absorption, distribution, metabolism and excretion in the body.

Pharmacopoeia Authoritative treatise containing directions for the identification of drug samples and the preparation of compound medicines and published by the authority of a government or a medical or pharmaceutical society and in a broader sense a general reference work for pharmaceutical drug specifications.

Pharyngitis, pharyngolaryngitis Inflammation of the pharynx and the larynx.

Pharyngolaryngeal Pertaining to the pharynx and larynx.

Phase-II drug-metabolising enzymes Play an important role in biotransformation of endogenous compounds and xenobiotics to more easily excretable forms as well as in the metabolic inactivation of pharmacologically active compounds. Phase-II drug-metabolising enzymes are mainly transferases.

Phenolics Class of chemical compounds consisting of a hydroxyl group (-OH) bonded directly to an aromatic hydrocarbon group.

Pheochromocytoma Is a rare neuroendocrine tumour that usually originates from the adrenal glands' chromaffin cells, causing overproduction of catecholamines, powerful hormones that induce high blood pressure and other symptoms.

Phlebitis Is an inflammation of a vein, usually in the legs.

Phlegm Abnormally viscid mucus secreted by the mucosa of the respiratory passages during certain infectious processes.

Phlegmon A spreading, diffuse inflammation of the soft or connective tissue due to infection by *Streptococci* bacteria.

Phonophobia Fear of loud sound.

Phoroglucinol A white, crystalline compound used as an antispasmodic, analytical reagent and decalcifier of bone specimens for microscopic examination.

Phosphatidylglycerol Is a glycerophospholipid found in pulmonary active surface lipoprotein and consists of a L-glycerol 3-phosphate backbone ester-bonded to either saturated or unsaturated fatty acids on carbons 1 and 2.

Phosphatidylinositol 3-kinases (PI 3-kinases or PI3Ks) A group of enzymes involved in cellular functions such as cell growth, proliferation, differentiation, motility, survival and intracellular trafficking, which in turn are involved in cancer.

Phosphatidylserine A phosphoglyceride phospholipid that is one of the key building blocks of cellular membranes, particularly in the nervous system. It is derived from soy lecithin.

Phosphaturia A urinary tract condition of excessive urine phosphorus, causing urine to appear cloudy or murky coloured; also called hypophosphatemia.

Phosphodiesterases A diverse family of enzymes that hydrolyse cyclic nucleotides and thus play a key role in regulating intracellular levels of the second messengers cAMP and cGMP and hence cell function.

Phosphoenolpyruvate C kinase (PEPCK) An enzyme in the lyase family used in the metabolic pathway of gluconeogenesis.

Phospholipase An enzyme that hydrolyses phospholipids into fatty acids and other lipophilic substances.

Phospholipase A2 (PLA2) A small lipolytic enzyme that releases fatty acids from the second carbon group of glycerol. Plays an essential role in the synthesis of prostaglandins and leukotrienes.

Phospholipase C Enzyme that cleaves phospholipase.

Phospholipase C gamma (PLC gamma) Enzyme that cleaves phospholipase in cellular proliferation and differentiation, and its enzymatic activity is upregulated by a variety of growth factors and hormones.

Phosphorus (P) Is an essential mineral that makes up 1 % of a person's total body weight and is found in the bones and teeth. It plays

an important role in the body's utilisation of carbohydrates and fats in the synthesis of protein for the growth, maintenance and repair of cells and tissues. It is also crucial for the production of ATP, a molecule the body uses to store energy. Main sources are meat and milk; fruits and vegetables provide small amounts.

Photoaging Is the term that describes damage to the skin caused by intense and chronic exposure to sunlight resulting in premature aging of the skin.

Photocarcinogenesis Represents the sum of a complex of simultaneous and sequential biochemical events that ultimately lead to the occurrence of skin cancer caused by exposure to the sun.

Photodermatoses Skin disorders caused by exposure to sunlight.

Photophobia Abnormal visual intolerance to light.

Photopsia An affection of the eye in which the patient perceives luminous rays, flashes, coruscations, etc.

Photosensitivity Sensitivity towards light.

Phthisis An archaic name for tuberculosis.

Phytohaemagglutinin A lectin found in plants that is involved in the stimulation of lymphocyte proliferation.

Phytonutrients Certain organic components of plants that are thought to promote human health. Fruit, vegetables, grains, legumes, nuts and teas are rich sources of phytonutrients. Phytonutrients are not 'essential' for life. Also called phytochemicals.

Phytosterols A group of steroid alcohols, cholesterol-like phytochemicals naturally occurring in plants like vegetable oils, nuts and legumes.

Pica The persistent eating of substances with no nutrition, such as dirt, chalk, sand, ice, clay or paint.

Piebaldism Rare autosomal dominant disorder of melanocyte development characterised by distinct patches of skin and hair that contain no pigment.

Piles See haemorrhoids.

PI3K Phosphoinositide 3-kinase.

PI13K/AKT signalling pathways Are involved in the modulation of cell survival, cell cycle progression and cellular growth in cancer.

Pityriasis lichenoides Is a rare skin disorder of unknown aetiology characterised by multiple papules and plaques.

PKC Protein kinase C, a membrane-bound enzyme that phosphorylates different intracellular proteins and raises intracellular Ca levels.

PKC delta inhibitors Protein kinase C delta inhibitors that induce apoptosis of haematopoietic cell lines.

Placebo A sham or simulated medical intervention.

Placode A platelike epithelial thickening in the embryo where some organ or structure later develops.

Plantar verruca Wart occurring on the sole of the foot.

Plasma The yellow-coloured liquid component of blood in which blood cells are suspended.

Plasma kallikrien A serine protease, synthesised in the liver and circulating in the plasma.

Plasmalemma Plasma membrane.

Plasmin A proteinase enzyme that is responsible for digesting fibrin in blood clots.

Plasminogen The proenzyme of plasmin, whose primary role is the degradation of fibrin in the vasculature.

Plasminogen activator inhibitor-1 (PAI-1) Also known as endothelial plasminogen activator inhibitor or serpin E1, is a serine protease inhibitor (serpin) that functions as the principal inhibitor of tissue plasminogen activator (tPA) and urokinase (uPA), the activators of plasminogen and hence fibrinolysis (the physiological breakdown of blood clots).

Plaster Poultice.

Platelet-activating factor (PAF) Is an acetylated derivative of glycerophosphorylcholine, released by basophils and mast cells in immediate hypersensitive reactions and macrophages and neutrophils in other inflammatory reactions. One of its main effects is to induce platelet aggregation.

Platelet-derived growth factor (PDGF) Is one of the numerous growth factors or proteins that regulate cell growth and division.

PLC gamma Phospholipase C gamma plays a central role in signal transduction.

Pleurisy Is an inflammation of the pleura, the lining of the pleural cavity surrounding the

lungs, which can cause painful respiration and other symptoms. Also known as pleuritis.

Pneumonia An inflammatory illness of the lung caused by bacteria or viruses.

Pneumotoxicity Damage to lung tissues.

Poliomyelitis Is a highly infectious viral disease that may attack the central nervous system and is characterised by symptoms that range from a mild non-paralytic infection to total paralysis in a matter of hours; also called polio or infantile paralysis.

Poly (ADP-ribose) polymerase (PARP) A protein involved in a number of cellular processes, especially DNA repair and programmed cell death.

Polyarthritis Is any type of arthritis which involves five or more joints.

Polychromatic erythrocyte (PCE) An immature red blood cell containing RNA that can be differentiated by appropriate staining techniques from a normochromatic erythrocyte (NCE) which lacks RNA.

Polycystic kidney disease Is a kidney disorder passed down through families in which multiple cysts form on the kidneys, causing them to become enlarged.

Polycystic ovary syndrome Imbalance of woman's sex hormone; this imbalance may cause changes in menstrual cycle, skin changes, small cysts in the ovary and problems in getting pregnant.

Polycythaemia A type of blood disorder characterised by the production of too many red blood cells.

Polymorphonuclear Having a lobed nucleus. Used especially of neutrophilic white blood cells.

Polyneuritis Widespread inflammation of the nerves.

Polyneuritis gallinarum A nervous disorder in birds and poultry.

Polyneuropathy Simultaneous malfunction of many peripheral nerves throughout the body.

Polyp A growth that protrudes from a mucous membrane.

Polyphagia Medical term for excessive hunger or eating.

Polyposis Describes a condition where there are a lot of polyps.

PolyQ disease Polyglutamine repeat diseases are neurodegenerative ailments elicited by glutamine-encoding CAG nucleotide expansions within endogenous human genes.

Polyuria A condition characterised by the passage of large volumes of urine with an increase in urinary frequency.

Pomade A thick oily dressing.

Porphyria A disorder wherein the body cannot convert naturally occurring compounds (prophyrins) into haem, which contains iron.

Porphyrin Any of a class of water-soluble, nitrogenous biological pigments, derivatives of which include the haemoproteins.

Postherpetic neuralgia (PHN) Is neuralgia (pain in the nerves) caused by the varicella herpes zoster virus. The pain may last for more than a month or more after a shingles infection occurred.

Postpartum depression Depression after pregnancy; also called postnatal depression.

Postprandial After mealtime.

Potassium (K) Is an element that's essential for the body's growth and maintenance. It's necessary to keep a normal water balance between the cells and body fluids for cellular enzyme activities and plays an essential role in the response of nerves to stimulation and in the contraction of muscles. Potassium is found in many plant foods and fish (tuna, halibut): chard, mushrooms, spinach, fennel, kale, mustard greens, Brussels sprouts, broccoli, cauliflower, cabbage winter squash, eggplant, cantaloupe, tomatoes, parsley, cucumber, bell pepper, turmeric, ginger root, apricots, strawberries, avocado and banana.

Poultice Is a soft moist mass, often heated and medicated, that is spread on cloth over the skin to treat an aching, inflamed or painful part of the body. Also called cataplasm.

PPARs Peroxisome proliferator-activated receptors – a group of nuclear receptor proteins that function as transcription factors regulating the expression of genes.

PR interval Is the time (in seconds) from the beginning of the P wave (onset of atrial depolarisation) to the beginning of the QRS complex.

Prebiotics A category of functional food, defined as non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one

or a limited number of bacteria in the colon and thus improve host health. *cf*. probiotics.

Pre-ecamplasia Toxic condition of pregnancy characterised by high blood pressure, abnormal weight gain, proteinuria and oedema.

Prenidatory phase Pre-implantation phase.

Prepubertal Before puberty; pertaining to the period of accelerated growth preceding gonadal maturity.

Pregnane X receptor (PXR; NR1I2) Is a ligand-activated transcription factor that plays a role not only in drug metabolism and transport but also in various other biological processes.

Pregnenolone A steroid hormone produced by the adrenal glands, involved in the steroidogenesis of other steroid hormones like progesterone, mineralocorticoids, glucocorticoids, androgens and oestrogens.

Prenidatory Referring to the time period between fertilisation and implantation.

Prenylated flavones Flavones with an isoprenyl group in the 8-position, has been reported to have good anti-inflammatory properties.

Presyncopal sensation State consisting of lightheadedness, muscular weakness, blurred vision and feeling faint.

Primiparous Relating to a woman who has given birth once.

Proangiogenic Promote angiogenesis (formation and development of new blood vessels).

Probiotication Enhancement with beneficial probitoic bacteria such as *Lactobacillus* species that can prevent the growth of intestinal pathogenic microflora.

Probiotics Are dietary supplements and live microorganisms containing potentially beneficial bacteria or yeasts that are taken into the alimentary system for healthy intestinal functions. *cf*. prebiotics.

Proctitis An inflammation of the rectum that causes discomfort, bleeding and, occasionally, a discharge of mucus or pus.

Procyanidin Also known as proathocyanidin, oligomeric proathocyanidin, leukocyanidin, leucoanthocyanin, is a class of flavanols found in many plants. It has antioxidant activity and plays a role in the stabilisation of collagen and maintenance of elastin.

Progestational Of or relating to the phase of the menstrual cycle immediately following ovulation, characterised by secretion of progesterone.

Proglottid One of the segments of a tapeworm.

Prognosis Medical term to describe the likely outcome of an illness.

Prokinetic Or gastroprokinetic, substance that enhances gastrointestinal motility by increasing the frequency of contractions in the small intestine or making them stronger.

Prolactin A hormone produced by the pituitary gland, it stimulates the breasts to produce milk in pregnant women. It is also present in males, but its role is not well understood.

Prolapse A common condition where the bladder, uterus and/or bowel protrudes into the vagina.

Prolapsus To fall or slip out of place.

Prolapus ani Eversion of the lower portion of the rectum and protruding through the anus, common in infancy and old age.

Proliferating cell nuclear antigen (PCNA) A new marker to study human colonic cell proliferation.

Proliferative vitreoretinopathy (PVR) A most common cause of failure in retinal reattachment surgery, characterised by the formation of cellular membrane on both surfaces of the retina and in the vitreous.

Prolyl-4-hydroxylase (P4H) Key enzyme in collagen synthesis.

Promastigote The flagellate stage in the development of trypanosomatid protozoa, characterised by a free anterior flagellum.

Promyelocytic leukaemia A subtype of acute myelogenous leukaemia (AML), a cancer of the blood and bone marrow.

Pro-oxidants Chemicals that induce oxidative stress, either through creating reactive oxygen species or inhibiting antioxidant systems.

Prophylaxis Prevention or protection against disease.

Proptosis See exophthalmos.

Prostacyclin A prostaglandin that is a metabolite of arachidonic acid, inhibits platelet aggregation and dilates blood vessels.

Prostaglandins A family of C 20 lipid compounds found in various tissues, associated with muscular contraction and the

inflammation response such as swelling, pain, stiffness, redness and warmth.

Prostaglandin E2 (PEG -2) One of the prostaglandins, a group of hormone-like substances that participate in a wide range of body functions such as the contraction and relaxation of smooth muscle, the dilation and constriction of blood vessels, control of blood pressure and modulation of inflammation.

Prostaglandin E synthase An enzyme that in humans is encoded by the glutathione-dependent PTGES gene.

Prostanoids Term used to describe a sub-class of eicosanoids (products of COX pathway) consisting of the prostaglandins (mediators of inflammatory and anaphylactic reactions), the thromboxanes (mediators of vasoconstriction) and the prostacyclins (active in the resolution phase of inflammation.)

Prostanoid EP 4 A prostaglandin receptor that may be involved in the neonatal adaptation of circulatory system, osteoporosis as well as initiation of skin immune responses.

Prostate A gland that surrounds the urethra at the bladder in the male.

Prostate cancer A disease in which cancer develops in the prostate, a gland in the male reproductive system. Symptoms include pain, difficulty in urinating, erectile dysfunction and other symptoms.

Prostate-specific antigen (PSA) A protein produced by the cells of the prostate gland.

Protein kinase C (PKC) A family of enzymes involved in controlling the function of other proteins through the phosphorylation of hydroxyl groups of serine and threonine amino acid residues on these proteins. PKC enzymes play important roles in several signal transduction cascades.

Protein tyrosine phosphatase (PTP) A group of enzymes that remove phosphate groups from phosphorylated tyrosine residues on proteins.

Proteinase A protease (enzyme) involved in the hydrolytic breakdown of proteins, usually by splitting them into polypeptide chains.

Proteinuria Means the presence of an excess of serum proteins in the urine.

Proteolysis Cleavage of the peptide bonds in protein forming smaller polypeptides. *adj*. proteolytic.

Proteomics The large-scale study of proteins, particularly their structures and functions.

Prothrombin Blood-clotting protein that is converted to the active form, factor IIa, or thrombin, by cleavage.

Prothyroid Good for thyroid function.

Protheolithic Proteolytic, see proteolysis.

Proto-oncogene A normal gene which, when altered by mutation, becomes an oncogene that can contribute to cancer.

Prurigo A general term used to describe itchy eruptions of the skin.

Pruritis Defined as an unpleasant sensation on the skin that provokes the desire to rub or scratch the area to obtain relief; itch, itching. *adj*. pruritic.

PSA Prostate-specific antigen, a protein which is secreted into ejaculate fluid by the healthy prostate. One of its functions is to aid sperm movement.

Psoriasis A common chronic, non-contagious autoimmune dermatosis that affects the skin and joints.

Psychoactive Having effects on the mind or behaviour.

Psychonautics Exploration of the psyche by means of approaches such as meditation, prayer, lucid dreaming, brain wave entrainment, etc.

Psychotomimetic Hallucinogenic.

Psychotropic Capable of affecting the mind, emotions and behaviour.

PTEN Phosphatase and tensin homologue, a tumour suppressor gene.

Ptosis Also known as drooping eyelid; caused by weakness of the eyelid muscle and damage to the nerves that control the muscles or looseness of the skin of the upper eyelid.

P13-K Is a lipid kinase enzyme involved in the regulation of a number of cellular functions such as cell growth, proliferation, differentiation, motility, survival and intracellular trafficking, which in turn are involved in cancer.

P13-K/AKT signalling pathway Shown to be important for an extremely diverse array of cellular activities – most notably cellular proliferation and survival.

Pthysis Silicosis with tuberculosis.

Ptosis Drooping of the upper eye lid.

PTP Protein tyrosine phosphatase.

PTPIB Protein tyrosine phosphatase 1B.

P21 Also known as cyclin-dependent kinase inhibitor 1 or CDK-interacting protein 1, is a potent cyclin-dependent kinase inhibitor.

Puerperal Pertaining to childbirth.

Puerperium Post-partum period.

Pulmonary embolism A blockage (blood clot) of the main artery of the lung.

Purgative A substance used to cleanse or purge, especially causing the immediate evacuation of the bowel.

Purpura Is the appearance of red or purple discolorations on the skin that do not blanch on applying pressure. Also called peliosis.

Purulent Containing pus discharge.

Purulent sputum Sputum containing or consisting of pus.

Pustule Small, inflamed, pus-filled lesions.

Pyelitis Acute inflammation of the pelvis of the kidney caused by bacterial infection.

Pyelonephritis An ascending urinary tract infection that has reached the pyelum (pelvis) of the kidney.

Pyoderma Bacterial skin infection.

Pyodermatitis Refers to inflammation of the skin.

Pyorrhoea See periodontitis.

Pyretic Referring to fever.

Pyrexia Fever of unknown origin.

Pyridoxal A chemical form of vitamin B6. See vitamin B6.

Pyridoxamine A chemical form of vitamin B6. See vitamin B6.

Pyridoxine A chemical form of vitamin B6. See vitamin B6.

Pyrolysis Decomposition or transformation of a compound caused by heat. *adj*. pyrolytic.

PYY peptide A 36 amino acid peptide secreted by L cells of the distal small intestine and colon that inhibits gastric and pancreatic secretion.

QSR complex Series of deflections in an electrocardiogram that represent electrical activity generated by ventricular depolarisation prior to contraction of the ventricle.

QT interval Is a measure of the time between the start of the Q wave and the end of the T wave in the heart's electrical cycle. A prolonged QT interval is a biomarker for ventricular tachyarrhythmias and a risk factor for sudden death.

Quorum sensing (QS) The control of gene expression in response to cell density, is used by both gram-negative and gram-positive bacteria to regulate a variety of physiological functions.

Radiculitis Inflammation of the radicle of a nerve.

Radiodermatitis A skin disease associated with prolonged exposure to ionising radiation.

Radiolysis The dissociation of molecules by radiation.

Radioprotective Serving to protect or aiding in protecting against the injurious effect of radiations.

RAD23B UV excision repair protein RAD23 homologue B.

RAGE Is the receptor for advanced glycation end products, a multiligand receptor that propagates cellular dysfunction in several inflammatory disorders, in tumours and in diabetes.

RAS See renin-angiotensin system or recurrent aphthous stomatitis.

Rash A temporary eruption on the skin, see uticaria.

Reactive oxygen species Species such as superoxide, hydrogen peroxide and hydroxyl radical. At low levels, these species may function in cell signalling processes. At higher levels, these species may damage cellular macromolecules (such as DNA and RNA) and participate in apoptosis (programmed cell death).

Rec A Is a 38 kDa *Escherichia coli* protein essential for the repair and maintenance of DNA.

Receptor for advanced glycation end products (RAGE) Is a member of the immunoglobulin superfamily of cell surface molecules; mediates neurite outgrowth and cell migration upon stimulation with its ligand, amphoterin.

Reticulocyte Non-nucleated stage in the development of the red blood cell.

Reticulocyte lysate Cell lysate produced from reticulocytes, used as an in-vitro translation system.

Reticuloendothelial system Part of the immune system, consists of the phagocytic cells located in reticular connective tissue, primarily monocytes and macrophages.

Recurrent aphthous stomatitis, or RAS Is a common, painful condition in which recurring ovoid or round ulcers affect the oral mucosa.

Redox homeostasis Is considered as the cumulative action of all free-radical reactions and antioxidant defenses in different tissues.

Refrigerant A medicine or an application for allaying heat, fever or its symptoms.

Renal calculi Kidney stones.

Renal interstitial fibrosis Damage sustained by the kidneys' renal tubules and interstitial capillaries due to accumulation of extracellular waste in the wall of the small arteries and arterioles.

Renal resistive index (RRI) Measures the resistance of renal arterial flow to the kidney.

Renin Also known as an angiotensinogenase, is an enzyme that participates in the body's renin-angiotensin system (RAS).

Renin-angiotensin system (RAS) Also called the renin-angiotensin-aldosterone system (RAAS), is a hormone system that regulates blood pressure and water (fluid) balance.

Reperfusion The restoration of blood flow to an organ or tissue that has had its blood supply cut off, as after a heart attack.

Reporter gene A transfected gene that produces a signal, such as green fluorescence, when it is expressed.

Resistin A cysteine-rich protein secreted by adipose tissue of mice and rats.

Resolutive A substance that induces subsidence of inflammation.

Resolvent Reduces inflammation or swelling.

Respiratory burst Is the rapid release of reactive oxygen species (superoxide radical and hydrogen peroxide) from different cells.

Resorb To absorb or assimilate a product of the body such as an exudate or cellular growth.

Restenosis Is the reoccurrence of stenosis, a narrowing of a blood vessel, leading to restricted blood flow.

Resveratrol Is a phytoalexin produced naturally by several plants when under attack by pathogens such as bacteria or fungi. It is a potent antioxidant found in red grapes and other plants.

Reticuloendothelial system Part of the immune system that consists of the phagocytic cells located in reticular connective tissue. Also called macrophage system or mononuclear phagocyte system.

Retinal ischaemia Is a common cause of visual impairment and blindness.

Retinitis pigmentosa (RP) An inherited, degenerative eye disease that causes severe vision impairment and may lead to blindness.

Retinol A form of vitamin A, see vitamin A.

Retinoblastoma protein A tumour suppressor protein that is dysfunctional in several major cancers.

Retinopathy A general term that refers to some form of non-inflammatory damage to the retina of the eye.

Revulsive Counter-irritant, used for swellings.

Reye's syndrome A potentially fatal disease that has numerous detrimental effects on many organs, especially the brain and liver, occurs commonly in children after a viral infection.

Rhabdomyolysis Breakdown of muscle fibres leading to the release of muscle fibre content (myoglobin) into the bloodstream.

Rheumatic Pertaining to rheumatism or to abnormalities of the musculoskeletal system.

Rheumatism, rheumatic disorder, rheumatic diseases Refers to various painful medical conditions which affect bones, joints, muscles, tendons. Rheumatic diseases are characterised by the signs of inflammation – redness, heat, swelling and pain.

Rheumatoid arthritis (RA) Is a chronic, systemic autoimmune disorder that most commonly causes inflammation and tissue damage in joints (arthritis) and tendon sheaths, together with anaemia.

Rhinitis Irritation and inflammation of some internal areas of the nose; the primary symptom of rhinitis is a runny nose.

Rhinopathy Disease or malformation of the nose.

Rhinoplasty Is surgery to repair or reshape the nose.

Rhinorrhoea Commonly known as a runny nose, characterised by an unusually significant amount of nasal discharge.

Rhinosinusitis Inflammation of the nasal cavity and sinuses.

Rho GTPases Rho-guanosine triphosphate hydrolase enzymes are molecular switches that regulate many essential cellular processes, including actin dynamics, gene transcription, cell cycle progression and cell adhesion.

Ribosome inactivating proteins Proteins that are capable of inactivating ribosomes.

Rickets Is a softening of the bones in children potentially leading to fractures and deformity.

Ringworm Dermatophytosis, a skin infection caused by fungus.

Roborant Restoring strength or vigour, a tonic.

Rotavirus The most common cause of infectious diarrhoea (gastroenteritis) in young children and infants, one of several viruses that causes infections called stomach flu.

Rubefacient A substance for external application that produces redness of the skin e.g. by causing dilation of the capillaries and an increase in blood.

Ryanodine receptor Intracellular Ca ++ channels in animal tissues like muscles and neurons.

S.C. Abbreviation for sub-cutaneous, beneath the layer of skin.

S-T segment The portion of an electrocardiogram between the end of the QRS complex and the beginning of the T wave. Elevation or depression of the S-T segment is the characteristic of myocardial ischaemia or injury and coronary artery disease.

Salve Medical ointment used to soothe the head or body surface.

Sapraemia See septicaemia.

Sarcoma Cancer of the connective or supportive tissue (bone, cartilage, fat, muscle, blood vessels) and soft tissues.

Sarcopenia Degenerative loss of skeletal muscle mass and strength associated with ageing.

Sarcoplasmic reticulum A special type of smooth endoplamic reticulum found in smooth and striated muscle.

SARS Severe acute respiratory syndrome, the name of a potentially fatal new respiratory disease in humans which is caused by the SARS coronavirus (SARS-CoV).

Satiety State of feeling satiated, fully satisfied (appetite or desire).

Scabies A transmissible ectoparasite skin infection characterised by superficial burrows, intense pruritus (itching) and secondary infection.

Scarlatina Scarlet fever, an acute, contagious disease caused by infection with group A streptococcal bacteria.

Schwann cells Or neurolemmocytes, are the principal supporing cells of the peripheral nervous system; they form the myelin sheath of a nerve fibre.

Schistosomiasis Is a parasitic disease caused by several species of fluke of the genus *Schistosoma*. Also known as bilharzia, bilharziosis or snail fever.

Schizophrenia A psychotic disorder (or a group of disorders) marked by severely impaired thinking, emotions and behaviours.

Sciatica A condition characterised by pain deep in the buttock often radiating down the back of the leg along the sciatic nerve.

Scleroderma A disease of the body's connective tissue. The most common symptom is a thickening and hardening of the skin, particularly of the hands and face.

Scrofula A tuberculous infection of the skin on the neck caused by the bacterium *Mycobacterium tuberculosis*.

Scrophulosis See scrofula.

Scurf Abnormal skin condition in which small flakes or sales become detached.

Scurvy A state of dietary deficiency of vitamin C (ascorbic acid), which is required for the synthesis of collagen in humans.

Secretagogue A substance that causes another substance to be secreted.

Sedative Having a soothing, calming or tranquilising effect; reducing or relieving stress, irritability or excitement.

Seizure The physical findings or changes in behaviour that occur after an episode of abnormal electrical activity in the brain.

Selectins Are a family of cell adhesion molecules; e.g. selectin-E, selectin –L, selectin P.

Selenium (Se) A trace mineral that is essential to good health but required only in tiny amounts; it is incorporated into proteins to make selenoproteins, which are important antioxidant enzymes. It is found in avocado, brazil nut, lentils, sunflower seeds, tomato, whole-grain cereals, seaweed, seafood and meat.

Sensorineural bradyacuasia Hearing impairment of the inner ear resulting from damage to the sensory hair cells or to the nerves that supply the inner ear.

Sepsis Potentially fatal whole-body inflammation caused by severe infection.

Sequela An abnormal pathological condition resulting from a disease, injury or trauma.

Serine proteinase Peptide hydrolases which have an active centre histidine and serine involved in the catalytic process.

Serotonergic Liberating, activated by or involving serotonin in the transmission of nerve impulses.

Serotonin A monoamine neurotransmitter synthesised in serotonergic neurons in the central nervous system.

Sepsis Is a potentially fatal medical condition characterised by a whole-body inflammatory response (called a systemic inflammatory response syndrome or SIRS) that is triggered by an infection.

Septicaemia A systemic disease associated with the presence and persistence of pathogenic microorganisms or their toxins in the blood.

Sequelae A pathological condition resulting from a prior disease, injury or attack.

Sexual potentiator Increases sexual activity and potency and enhances sexual performance due to increased blood flow and efficient metabolism.

Sexually transmitted diseases (STD) Infections that are transmitted through sexual activity.

SGOT, serum glutamic oxaloacetic transaminase An enzyme that is normally present in liver and heart cells. SGOT is released into blood when the liver or heart is damaged. Also called aspartate transaminase (AST).

SGPT, serum glutamic pyruvic transaminase An enzyme normally present in serum and body tissues, especially in the liver; it is released into the serum as a result of tissue injury, also called alanine transaminase (ALT).

Shiga–like toxin A toxin produced by the bacterium *Escherichia coli* which disrupts the function of ribosomes, also known as verotoxin.

Shiga toxigenic *Escherichia coli* (STEC) Comprises a diverse group of organisms capable of causing severe gastrointestinal disease in humans.

Shiga toxin A toxin produced by the bacterium *Shigella dysenteriae*, which disrupts the function of ribosomes.

Shingles Skin rash caused by the zoster virus (same virus that causes chickenpox) and is medically termed herpes zoster.

Sialogogue Salivation promoter, a substance used to increase or promote the excretion of saliva.

Sialoproteins Glycoproteins that contain sialic acid as one of their carbohydrates.

Sialorrhoea Excessive production of saliva.

Sialyation Reaction with sialic acid or its derivatives; used especially with oligosaccharides.

Sialyltransferases Enzymes that transfer sialic acid to nascent oligosaccharides.

Sickle-cell disease Is an inherited blood disorder that affects red blood cells. People with sickle-cell disease have red blood cells that contain mostly haemoglobin S, an abnormal type of haemoglobin. Sometimes, these red blood cells become sickle shaped (crescent shaped) and have difficulty passing through small blood vessels.

Side stitch Is an intense stabbing pain under the lower edge of the ribcage that occurs while exercising.

Signal transduction cascade Refers to a series of sequential events that transfer a signal through a series of intermediate molecules until final regulatory molecules, such as transcription factors, are modified in response to the signal.

Silicon (Si) Is required in minute amounts by the body and is important for the development of healthy hair and the prevention of nervous disorders. Lettuce is the best natural source of silicon.

Sinapism Signifies an external application, in the form of a soft plaster, or poultice.

Sinusitis Inflammation of the nasal sinuses.

SIRC cells Statens seruminstitut rabbit cornea (SIRC) cell line.

SIRT 1 Stands for sirtuin (silent mating type information regulation 2 homologue) 1. It is an enzyme that deacetylates proteins that contribute to cellular regulation.

Sirtuin Also called Sir2 proteins, a class of proteins that possess either histone deacetylase or mono-ribosyltransferase activity.

6-Keto-PGF1 alpha A physiologically active and stable hydrolysis product of epoprostenol, found in nearly all mammalian tissues.

Sjögren's syndrome An autoimmune disease that mainly affects the eyes and salivary glands but can affect different parts of the body.

Skp1 (S-phase kinase-associated protein 1) is a core component of SCF ubiquitin ligases and mediates protein degradation.

Smads A family of intracellular proteins that mediate signalling by members of the TGF-beta (transforming growth factor beta) super-family.

Smad2/3 A key signalling molecule for TGF-beta.

Smad7 A TGFβ type 1 receptor antagonist.

Smallpox Is an acute, contagious and devastating disease in humans caused by *Variola* virus and has resulted in high mortality over the centuries.

Snuff Powder inhaled through the nose.

SOCE (store-operated $Ca2^+$ entry) Is a receptor-regulated $Ca2^+$ entry pathway.

SOD Super-oxide dismutase, is an enzyme that repairs cells and reduces the damage done to them by superoxide, the most common free radical in the body.

Sodium (Na) Is an essential nutrient required for health. Sodium cations are important in neuron (brain and nerve) function and in influencing osmotic balance between cells and the interstitial fluid and in maintenance of total body fluid homeostasis. Extra intake may cause a harmful effect on health. Sodium is naturally supplied by salt intake with food.

Soleus muscle Smaller calf muscle lower down the leg and under the gastrocnemius muscle.

Somites Mesodermal structures formed during embryonic development that give rise to segmented body parts such as the muscles of the body wall.

Soporific A sleep-inducing drug.

SOS response A global response to DNA damage in which the cell cycle is arrested and DNA repair and mutagenesis are induced.

Soyasapogenins Triterpenoid products obtained from the acid hydrolysis of soyasaponins, designated soyasapogenols A, B, C, D and E.

Soyasaponins Bioactive saponin compounds found in many legumes.

Spasmogenic Inducing spasm.

Spasmolytic Checking spasms, see antispasmodic.

Spermatogenic Giving rise to sperms.

Spermatorrhoea Medically, an involuntary ejaculation/drooling of semen, usually nocturnal emissions.

Spermidine An important polyamine in DNA synthesis and gene expression.

Spina bifida A congenital birth defect caused by the incomplete closing of the embryonic neural tube.

Sphingolipid A member of a class of lipids derived from the aliphatic amino alcohol sphingosine.

Spinocerebellar ataxia (SCA) Is a progressive, degenerative genetic disease with multiple types.

Spleen Organ that filters blood and prevents infection.

Spleen tyrosine kinase (SYK) Is an enigmatic protein tyrosine kinase functional in a number of diverse cellular processes such as the regulation of immune and inflammatory responses.

Splenitis Inflammation of the spleen.

Splenocyte Is a monocyte, one of the five major types of white blood cell, and is characteristically found in the splenic tissue.

Splenomegaly Is an enlargement of the spleen.

Sprain To twist a ligament or muscle of a joint without dislocating the bone.

Sprue Is a chronic disorder of the small intestine caused by sensitivity to gluten, a protein found in wheat and rye and to a lesser extent in oats and barley. It causes poor absorption by the intestine of fat, protein, carbohydrates, iron, water and vitamins A, D, E and K.

Sputum Matter coughed up and usually ejected from the mouth, including saliva, foreign material and substances such as mucus or phlegm from the respiratory tract.

SREBP-1 See sterol regulatory element-binding protein-1.

Stanch To stop or check the flow of a bodily fluid like blood from a wound.

Statin A type of lipid-lowering drug.

STAT3 Signal transducer and activator of transcription 3, a transcription factor, plays a key role in many cellular processes such as cell growth and apoptosis.

Status epilepticus Refers to a life-threatening condition in which the brain is in a state of persistent seizure.

STD Sexually transmitted disease.

Steatorrhoea Is the presence of excess fat in faeces which appear frothy and foul smelling and float because of the high fat content.

Steatohepatitis Liver disease, characterised by inflammation of the liver with fat accumulation in the liver.

Steatosis Refers to the deposition of fat in the interstitial spaces of an organ like the liver, fatty liver disease.

Stereotypy Excessive repetitive or ritualistic movement, posture or utterance.

Sterility Inability to produce offspring, also called asepsis.

Steroidogenic Relating to steroidogenesis.

Steroidogenesis The production of steroids, as by the adrenal glands.

Sterol-regulatory element-binding protein-1 (SREBP1) Is a key regulator of the transcription of numerous genes that function in the metabolism of cholesterol and fatty acids.

Stimulant A substance that promotes the activity of a body system or function.

Stomachic Digestive stimulant, an agent that stimulates or strengthens the activity of the stomach; used as a tonic to improve the appetite and digestive processes.

Stomatitis Oral inflammation and ulcers, may be mild and localised or severe, widespread and painful.

Stomatology Medical study of the mouth and its diseases.

Stool Faeces.

Strangury Is the painful passage of small quantities of urine which are expelled slowly by straining with severe urgency; it is usually accompanied with the unsatisfying feeling of a remaining volume inside and a desire to pass something that will not pass.

Straub tail Condition in which an animal carries its tail in an erect (vertical or nearly vertical) position.

STREPs Sterol-regulatory element-binding proteins, a family of transcription factors that regulate lipid homeostasis by controlling the expression of a range of enzymes required for endogenous cholesterol, fatty acid, triacylglycerol and phospholipid synthesis.

Stria terminalis A structure in the brain consisting of a band of fibres running along the lateral margin of the ventricular surface of the thalamus.

Striae gravidarum A cutaneous condition characterised by stretch marks on the abdomen during and following pregnancy.

Stricture An abnormal constriction of the internal passageway within a tubular structure such as a vessel or duct.

Strongyloidiasis An intestinal parasitic infection in humans caused by two species of the parasitic nematode *Strongyloides*. The nematodes or roundworms are also called threadworms.

Styptic A short stick of medication, usually anhydrous aluminum sulphate (a type of alum) or titanium dioxide, which is used for stanching blood by causing blood vessels to contract at the site of the wound. Also called haemostatic pencil, see antihaemorrhagic.

Subarachnoid haemorrhage Is bleeding in the area between the brain and the thin tissues that cover the brain.

Substance P A neuropeptide that functions as a neurotransmitter and neuromodulator and is associated with the sensation of pain.

Substantia nigra Is a dark-coloured brain structure located in the midbrain that plays an important role in reward, addiction and movement.

Sudatory Medicine that causes or increases sweating. Also see sudorific.

Sudorific A substance that causes sweating.

Sulphur Sulphur is an essential component of all living cells. Sulphur is important for the synthesis of sulphur-containing amino acids, all polypeptides, proteins and enzymes such as glutathione an important sulphur-containing tripeptide which plays a role in cells as a source of chemical reduction potential. Sulphur is also important for hair formation. Good plant sources are garlic, onion, leeks and other alliaceous vegetables, brassicaceous vegetables like cauliflower, cabbages, Brussels sprout, kale; legumes – beans, green and red gram, soybeans; horseradish, water cress and wheat germ.

Superior mesenteric artery (SMA) Arises from the anterior surface of the abdominal aorta, just inferior to the origin of the celiac trunk, and supplies the intestine from the lower part of the duodenum to the left colic flexure and the pancreas.

Superoxide mutase (SOD) Antioxidant enzyme.

Suppuration The formation of pus, the act of becoming converted into and discharging pus.

Supraorbital Located above the orbit of the eye.

Sural nerve Sensory nerve comprising collateral branches off the common tibial and common fibular nerve.

SYK, spleen tyrosine kinase Is a human protein and gene. Syk plays a similar role in transmitting signals from a variety of cell surface receptors including CD74, Fc receptor and integrins.

Sympathetic nervous system The part of the autonomic nervous system originating in the thoracic and lumbar regions of the spinal cord that in general inhibits or opposes the physiological effects of the parasympathetic nervous system, as in tending to reduce digestive secretions or speed up the heart.

Sympathomimetic Mimicking the effects of impulses conveyed by adrenergic postganglionic fibres of the sympathetic nervous system.

Synaptic plasticity The ability of neurons to change the number and strength of their synapses.

Synaptogenesis The formation of synapses.

Synaptoneurosomes Purified synapses containing the pre- and post-synaptic termini.

Synaptosomes Isolated terminal of a neuron.

Syncope Fainting, sudden loss of consciousness followed by the return of wakefulness.

Syndactyly Webbed toes, a condition where two or more digits are fused together.

Syneresis Expulsion of liquid from a gel, as contraction of a blood clot and expulsion of liquid.

Syngeneic Genetically identical or closely related, so as to allow tissue transplant; immunologically compatible.

Synovial Lubricating fluid secreted by synovial membranes, as those of the joints.

Synoviocyte Located in the synovial membrane; there are two types. Type A cells are more numerous, have phagocytic characteristics and produce degradative enzymes. Type B cells produce synovial fluid, which lubricates the joint and nurtures and nourishes the articular cartilage.

Syphilis Is perhaps the best known of all the STDs. Syphilis is transmitted by direct contact with infection sores, called chancres, syphitic skin rashes or mucous patches on the tongue and mouth during kissing, necking, petting or sexual intercourse. It can also be transmitted from a pregnant woman to a fetus after the fourth month of pregnancy.

System lupus erythematosus A long-term autoimmune disorder that may affect the skin, joints, kidneys, brain and other organs. Symptoms may include chest pain, fatigue, fever, hair loss, mailaise, mouth sores, sensitivity to sunlight and skin rash (buttefly rash).

Systolic The blood pressure when the heart is contracting. It is specifically the maximum arterial pressure during contraction of the left ventricle of the heart.

T cells Or T lymphocytes, a type of white blood cell that play a key role in the immune system.

Tachyarrhythmia Any disturbance of the heart rhythm in which the heart rate is abnormally increased.

Tachycardia A false heart rate applied to adults to rates over 100 beats per minute.

Tachykinins Neuropeptide transmitters that are widely distributed and active in the central nervous system and periphery, rapidly acting secretagogues and cause smooth muscle contraction and vasodilation (hypotension).

Tachyphylaxia A decreased response to a medicine given over a period of time so that larger doses are required to produce the same response.

Tachypnea Abnormally fast breathing.

Taenia A parasitic apeworm or flatworm of the genus *Taenia*.

Taeniacide An agent that kills tapeworms.

Tardive dyskinesia A disorder characterised by repetitive, involuntary, purposeless movements in the body such as grimacing, tongue protrusion, lip smacking, puckering and pursing of the lips and rapid eye blinking. Rapid, involuntary movements of the limbs, torso and fingers may also occur.

Tau Is a class of microtubule-associated protein (MAP) in neuronal and glial cells.

Tau-1 (Ser198/199/202), pS396 (Ser396) and pS214 (Ser214) epitopes Serine phosphorylation sites of tau-1.

Tau phosphorylation Plays an important role in neuro-degenerative diseases and is regulated by protein kinases and phosphatases.

TBARS See thiobarbituric acid reactive substances.

T cell A type of white blood cell that attacks virus-infected cells, foreign cells and cancer cells.

TCA cycle See tricarboxylic acid cycle.

TCID50 Median tissue culture infective dose; that amount of a pathogenic agent that will produce pathological change in 50 % of cell cultures.

Telencephalon The cerebral hemispheres, the largest divisions of the human brain.

Teletherapy A non-invasive procedure using external beam radiotherapy treatments.

Telomerase Enzyme that acts on parts of chromosomes known as telomeres.

Temporomandibular joint disorder (TMJD or TMD syndrome) A disorder characterised by acute or chronic inflammation of the temporomandibular joint that connects the mandible to the skull.

Tendonitis Is inflammation of a tendon.

Tenesmus A strong desire to defaecate.

Teratogen Is an agent that can cause malformations of an embryo or fetus. *adj*. teratogenic.

Testicular torsion Twisting of the spermatic cord, which cuts off the blood supply to the testicle and surrounding structures within the scrotum.

Tetanus An acute, potentially fatal disease caused by tetanus bacilli multiplying at the site of an injury and producing an exotoxin that reaches the central nervous system producing prolonged contraction of skeletal muscle fibres. Also called lockjaw.

Tete Acute dermatitis caused by both bacterial and fungal infection.

Tetter Any of a number of skin diseases.

TGF-beta Transforming growth factor beta is a protein that controls proliferation, cellular differentiation and other functions in most cells.

Th cells or T helper cells A sub-group of lymphocytes that helps other white blood cells in immunological processes.

Th 1 cells Helper cells that play an important role in the immune system.

Th 17 cells A sub-set of T helper cells producing interleukin 17.

Thalassemia major Is a genetic blood disorder that causes the body to manufacture an abnormal form of haemoglobin.

Thelarche The beginning of secondary (postnatal) breast development, usually occurring at the beginning of puberty in girls.

Thermogenic Tending to produce heat, applied to drugs or food (fat-burning food).

Thermogenesis Is the process of heat production in organisms.

Thermonociceptors Or thermal nociceptors, sensory receptors that are stimulated by noxious heat or cold at various temperatures.

Thiobarbituric acid reactive substances (TBARS) A well-established method for screening and monitoring lipid peroxidation.

Thixotropy The property exhibited by certain gels of becoming fluid when stirred or shaken and returning to the semisolid state upon standing.

Thoracodynia Pain in the chest.

3-β-HSD (Or 3-β-hydroxysteroid dehydrogenase/δ-5-4 isomerase) is an enzyme that catalyses the synthesis of progesterone from pregnenolone.

3-nitrotyrosine (3-NT) protein Used as a marker for oxidative damage or nitrosative stress.

Thrombocythaemia A blood condition characterised by a high number of platelets in the blood.

Thrombocytopenia A condition when the bone marrow does not produce enough platelets (thrombocytes) like in leukaemia.

Thromboembolism Formation in a blood vessel of a clot (thrombus) that breaks loose and is carried by the bloodstream to plug another vessel. *cf.* deep-vein thrombosis.

Thrombogenesis Formation of a thrombus or blood clot.

Thrombophlebitis Occurs when there is inflammation and clot in a surface vein.

Thromboplastin An enzyme liberated from blood platelets that converts prothrombin into thrombin as blood starts to clot, also called thrombokinase.

Thrombosis The formation or presence of a thrombus (clot).

Thromboxanes Any of several compounds, originally derived from prostaglandin precursors in platelets that stimulate aggregation of platelets and constriction of blood vessels.

Thromboxane B2 The inactive product of thromboxane.

Thrombus A fibrinous clot formed in a blood vessel or in a chamber of the heart.

Thrush A common mycotic infection caused by yeast, *Candida albicans*, in the digestive tract or vagina. In children, it is characterised by white spots on the tongue.

Thymocytes Are T-cell precursors which develop in the thymus.

Thyrotoxicosis Or hyperthyroidism – an overactive thyroid gland, producing excessive circulating free thyroxine, free triiodothyronine or both.

Tight junction Associated areas of two cells whose membranes join together forming a virtually impermeable barrier to fluid.

TIMP-3 A human gene belonging to the tissue inhibitor of matrix metalloproteinases (MMP) gene family. See MMP.

Tincture Solution of a drug in alcohol.

Tinea Ringworm, fungal infection on the skin.

Tinea favosa See favus.

Tinea cruris Ringworm of the groin.

Tinea imbricata (Also called Tokelau) an eruption characterised by concentric rings of overlapping scales forming papulosquamous patches scattered over the body; it occurs in tropical climates especially prevalent in southwest Polynesia and is caused by the fungus *Trichophyton concentricum*.

Tinea pedis Fungal infection of the foot, also called athletes' foot.

Tinnitus A noise in the ears, as ringing, buzzing, roaring, clicking, etc.

Tisane A herbal infusion used as tea or for medicinal purposes.

Tissue plasminogen activator (t-PA) A serine protease involved in the breakdown of blood clots.

TNF alpha Cachexin or cachectin and formally known as tumour necrosis factor-alpha, a cytokine involved in systemic inflammation. The primary role of TNF is in the regulation of immune cells. TNF is also able to induce apoptotic cell death, to induce inflammation and to inhibit tumorigenesis and viral replication.

Tocolytics Medications used to suppress premature labour.

Tocopherol Fat-soluble organic compound belonging to vitamin E group. See vitamin E.

Tocotrienol Fat-soluble organic compound belonging to vitamin E group. See vitamin E.

Tolerogenic Producing immunological tolerance.

Toll-like receptors (TLRs) A class of proteins that play a key role in the innate immune system.

Tonic Substance that acts to restore, balance, tone, strengthen or invigorate a body system without overt stimulation or depression.

Tonic clonic seizure A type of generalised seizure that affects the entire brain.

Tonsillitis An inflammatory condition of the tonsils due to bacteria, allergies or respiratory problems.

TOP2A Topoisomerase II alpha enzyme.

Topoisomerases A class of enzymes involved in the regulation of DNA super-coiling.

Topoiosmerase inhibitors A new class of anticancer agents with a mechanism of action aimed at interrupting DNA replication in cancer cells.

Total parenteral nutrition (TPN) Is a method of feeding that bypasses the gastrointestinal tract.

Toxemia Is the presence of abnormal substances in the blood, but the term is also used for a serious condition in pregnancy that involves hypertension and proteinuria. Also called pre-eclampsia.

Tracheitis Is a bacterial infection of the trachea; also known as bacterial tracheitis or acute bacterial tracheitis.

Trachoma A contagious disease of the conjunctiva and cornea of the eye, producing painful sensitivity to strong light and excessive tearing.

TRAIL Acronym for tumour necrosis factor-related apoptosis-inducing ligand, is a cytokine that preferentially induces apoptosis in tumour cells.

Tranquiliser A substance drug used in calming a person suffering from nervous tension or anxiety.

Transaminase Also called aminotransferase, is an enzyme that catalyses a type of reaction between an amino acid and an α-keto acid.

Transaminitis Increase in alanine aminotransferase (ALT) and/or aspartate aminotransferase (AST) to >5 times the upper limit of normal.

Transcatheter arterial chemoembolisation (TACE) Is an interventional radiology procedure involving percutaneous access to the hepatic artery and passing a catheter through the abdominal artery aorta followed by radiology. It is used extensively in the palliative treatment of unresectable hepatocellular carcinoma (HCC).

Transcriptional activators Are proteins that bind to DNA and stimulate transcription of nearby genes.

Transcriptional co-activator PGC-1 A potent transcriptional co-activator that regulates oxidative metabolism in a variety of tissues.

Transcriptome profiling To identify genes involved in peroxisome assembly and function.

Transforming growth factor beta (TGF-β) A protein that controls proliferation, cellular differentiation and other functions in most cells.

Transient receptor potential ankyrin 1 (TRPA1) Is a Ca(2+)-permeant, non-selective cationic channel that may play a role in nociception.

Transient receptor potential vanilloid 1 (TRPV1) Receptor also known as capsaicin receptor and vanilloid receptor, is a Ca 2+ permeable non-selective cation channel localised on a sub-set of primary sensory neurons that can be activated by physical and chemical stimuli.

TRAP 6 Thrombin receptor activating peptide with six amino acids.

Tremorine A chemical that produces a tremor resembling Parkinsonian tremor.

Tremulous Marked by trembling, quivering or shaking.

Triacylglycerol Or triacylglyceride, is a glyceride in which the glycerol is esterified with three fatty acids.

Tricarboxylic acid cycle (TCA cycle) A series of enzymatic reactions in aerobic organisms involving oxidative metabolism of acetyl units and producing high-energy phosphate compounds, which serve as the main source of cellular energy. Also called citric acid cycle, Krebs cycle.

Trichophytosis Infection by fungi of the genus *Trichophyton*.

Trigeminal neuralgia (TN) Is a neuropathic disorder of one or both of the facial trigeminal nerves, also known as prosopalgia.

Triglycerides A type of fat (lipids) found in the bloodstream.

Trismus Continuous contraction of the muscles of the jaw, specifically as a symptom of tetanus, or lockjaw; inability to open the mouth fully.

TrKB receptor Also known as TrKB tyrosine kinase, a protein in humans that acts as a catalytic receptor for several neutrophins.

Trolox equivalent Measures the antioxidant capacity of a given substance, as compared to the standard; Trolox is also referred to as TEAC (Trolox equivalent antioxidant capacity).

Trypanocidal Destructive to trypanosomes.

Trypanosomes Protozoan of the genus *Trypanosoma*.

Trypanosomiasis Human disease or an infection caused by a trypanosome.

Trypsin An enzyme of pancreatic juice that hydrolyses proteins into smaller polypeptide units.

Trypsin inhibitor Small protein synthesised in the exocrine pancreas which prevents conversion of trypsinogen to trypsin, so protecting itself against trypsin digestion.

TRPV1 See transient receptor potential vanilloid 1.

Tuberculosis (TB) Is a bacterial infection of the lungs caused by a bacterium called *Mycobacterium tuberculosis*, characterised by the formation of lesions (tubercles) and necrosis in the lung tissues and other organs.

Tumorigenesis Formation or production of tumours.

Tumour An abnormal swelling of the body other than that caused by direct injury.

Tussis A cough.

Tympanic membrane Ear drum.

Tympanitis Infection or inflammation of the inner ear.

Tympanophonia Increased resonance of one's own voice, breath sounds, arterial murmurs, etc., noted especially in disease of the middle ear.

Tympanosclerosis See myringoslcerosis.

Tyrosinase A copper-containing enzyme found in animals and plants that catalyses the oxidation of phenols (such as tyrosine) and the production of melanin and other pigments from tyrosine by oxidation.

Ubiquitin ligase Also called an E3 ubiquitin ligase, is a protein that targets other proteins to be broken down (degraded) within cells.

UCP1 An uncoupling protein found in the mitochondria of brown adipose tissue used to generate heat by non-shivering thermogenesis.

UCP – 2 enzyme Uncoupling protein 2 enzyme, a mitochondrial protein expressed in adipocytes.

Ulcer An open sore on an external or internal body surface usually accompanied by disintegration of tissue and pus.

Ulcerative colitis Is one of two types of inflammatory bowel disease – a condition that causes the bowel to become inflamed and red.

Ulemorrhagia Bleeding of the gums.

Ulitis Inflammation of the gums.

Unguent Ointment.

Unilateral ureteral obstruction Unilateral blockage of urine flow through the ureter of one kidney, resulting in a backup of urine, distension of the renal pelvis and calyces and hydronephrosis.

Uraemia An excess in the blood of urea, creatinine and other nitrogenous end products of protein and amino acid metabolism, more correctly referred to as azotaemia.

Urethra Tube conveying urine from the bladder to the external urethral orifice.

Urethritis Is an inflammation of the urethra caused by infection.

Uricemia An excess of uric acid or urates in the blood.

Uricosuric Promoting the excretion of uric acid in urine.

Urinary Pertaining to the passage of urine.

Urinary incontinence Sudden and strong need to urinate because of poor bladder control.

Urinogenital Relating to genital and urinary organs or functions.

Urodynia Pain on urination.

Urokinase Also called urokinase-type palsminogen (u-PA), is a serine protease enzyme in human urine that catalyses the conversion of plasminogen to plasmin. It is used clinically as a thrombolytic agent.

Urokinase-type palsminogen (u-PA) Plays a key role in tumour invasion and metastasis, also see Urokinase.

Urolithiasis Formation of stones in the urinary tract (kidney, bladder or urethra).

Urticant A substance that causes wheals to form.

Urticaria Or hives, is a skin condition, commonly caused by an allergic reaction, that is characterised by raised red skin welts.

Uterine Relating to the uterus.

Uterine myomas Also called fibroids, tumours that grow from the uterine wall.

Uterine prolapse Occurs when weakened or damaged muscles and ligaments allow the uterus to slip into the vagina.

Uterine relaxant An agent that relaxes the muscles in the uterus.

Uterine stimulant An agent that stimulates the uterus (and often employed during active childbirth).

Uterotonic Giving muscular tone to the uterus.

Uterotrophic Causing an effect on the uterus.

Uterus Womb.

Vaginal dystrophy A condition in which the outer part of the vagina becomes dry and the skin thickens or thins.

Vaginitis Infectious or non-infectious inflammation of the vaginal mucosa.

Vaginopathy Any disease of the vagina.

Vagotomy The surgical cutting of the vagus nerve to reduce acid secretion in the stomach.

Vagus nerve A cranial nerve, that is, a nerve connected to the brain. The vagus nerve has branches to most of the major organs in the body, including the larynx, throat, windpipe, lungs, heart and most of the digestive system.

Variola Or smallpox, a contagious disease unique to humans, caused by either of two virus variants, *Variola major* and *Variola minor*. The disease is characterised by fever, weakness and skin eruption with pustules that form scabs that leave scars.

Varicose veins Are veins that have become enlarged and twisted.

Vasa vasorum Is a network of small blood vessels that supply large blood vessels. *plur*. vasa vasori.

Vascular endothelial growth factor (VEGF) A polypeptide chemical produced by cells that stimulates the growth of new blood vessels.

Vasculitis Group of disorders that destroy blood vessels by inflammation.

Vasculogenesis The process of blood vessel formation occurring by a de novo production of endothelial cells.

Vasoconstrictor Drug that causes constriction of blood vessels.

Vasodilator Drug that causes dilation or relaxation of blood vessels.

Vasodilatory Causing the widening of the lumen of blood vessels.

Vasomotor symptoms Menopausal symptoms characterised by hot flushes and night sweats.

Vasospasm Refers to a condition in which blood vessels spasm, leading to vasoconstriction and subsequently to tissue ischaemia and death (necrosis).

VCAM-1 (vascular cell adhesion molecule-1) Also known as CD106, contains six or seven immunoglobulin domains and is expressed on both large and small vessels only after the endothelial cells are stimulated by cytokines.

VEGF Vascular endothelial growth factor.

Venereal disease (VD) Term given to the diseases syphilis and gonorrhoea.

Venule A small vein, especially one joining capillaries to larger veins.

Vermifuge A substance used to expel worms from the intestines.

Verotoxin A Shiga-like toxin produced by *Escherichia coli*, which disrupts the function of ribosomes, causing acute renal failure.

Verruca A contagious and painful wart on the sole of the foot.

Verruca plana Is a reddish-brown or flesh-coloured, slightly raised, flat-surfaced, well-demarcated papule on the hand and face, also called flat wart.

Verruca vulgaris Small painless warts on the skin caused by the human papillomavirus.

Vertigo An illusory, sensory perception that the surroundings or one's own body are revolving; dizziness.

Very-low-density lipoprotein (VLDL) A type of lipoprotein made by the liver. VLDL is one of the five major groups of lipoproteins (chylomicrons, VLDL, intermediate-density lipoprotein, low-density lipoprotein, high-density lipoprotein (HDL)) that enable fats and cholesterol to move within the water-based solution of the bloodstream. VLDL is converted in the bloodstream to low-density lipoprotein (LDL).

Vesical calculus Calculi (stones) in the urinary bladder.

Vesicant A substance that causes tissue blistering.

Vestibular Relating to the sense of balance.

Vestibular disorders Includes symptoms of dizziness, vertigo and imbalance; it can result from or be worsened by genetic or environmental conditions.

Vestibular schwannoma Also called acoustic neuroma, is a benign tumour that may develop from an overproduction of Schwann cells that press on the hearing and balance nerves in the inner ear.

Vestibular system Includes parts of the inner ear and brain that process sensory information involved with controlling balance and eye movement.

Vibrissa Stiff hairs that are located especially about the nostrils.

Vimentin A type III intermediate filament protein that is expressed in mesenchymal cells.

Viremia A medical condition where viruses enter the bloodstream and hence have access to the rest of the body.

Visceral fat Intra-abdominal fat, is located inside the peritoneal cavity, packed in between internal organs and torso.

Visual entopia Visual disturbances.

Vitamin Any complex organic compound found in various foods or sometimes synthesised in the body, required in tiny amounts and essential for the regulation of metabolism, normal growth and function of the body.

Vitamin A Retinol, fat-soluble vitamins that play an important role in vision, bone growth, reproduction, cell division and cell differentiation, helps regulate the immune system in preventing or fighting off infections. Vitamin A that is found in colourful fruit and vegetables is called provitamin A carotenoid. They can be made into retinol in the body. Deficiency of vitamin A results in night blindness and keratomalacia.

Vitamin B1 Also called thiamine, water-soluble vitamins, dissolve easily in water and, in general, are readily excreted from the body; they are not readily stored; consistent daily intake is important. It functions as co-enzyme in the metabolism of carbohydrates and branched-chain amino acids and other cellular processes. Deficiency results in beriberi disease.

Vitamin B2 Also called riboflavin, an essential water-soluble vitamin that functions as

co-enzyme in redox reactions. Deficiency causes ariboflavinosis.

Vitamin B3 Comprises niacin and niacinamide, water-soluble vitamins that function as co-enzyme or co-substrate for many redox reactions, and is required for energy metabolism. Deficiency causes pellagra.

Vitamin B5 Also called pantothenic acid, a water-soluble vitamin that functions as co-enzyme in fatty acid metabolism. Deficiency causes paresthesia.

Vitamin B6 Water-soluble vitamin, exists in three major chemical forms: pyridoxine, pyridoxal and pyridoxamine. Vitamin B6 is needed in enzymes involved in protein metabolism, red blood cell metabolism, efficient functioning of nervous and immune systems and haemoglobin formation. Deficiency causes anaemia and peripheral neuropathy.

Vitamin B7 Also called biotin or vitamin H, an essential water-soluble vitamin, is involved in the synthesis of fatty acids, amino acids and glucose in energy metabolism. Biotin promotes normal health of sweat glands, bone marrow, male gonads, blood cells, nerve tissue, skin and hair. Deficiency causes dermatitis and enteritis.

Vitamin B9 Also called folic acid, an essential water-soluble vitamin. Folate is especially important during periods of rapid cell division and growth such as infancy and pregnancy. Deficiency during pregnancy is associated with birth defects such as neural tube defects. Folate is also important for production of red blood cells and prevent anaemia. Folate is needed to make DNA and RNA, the building blocks of cells. It also helps prevent changes to DNA that may lead to cancer.

Vitamin B12 A water-soluble vitamin, also called cobalamin as it contains the metal cobalt. It helps maintain healthy nerve cells and red blood cells and DNA production. Vitamin B12 is bound to the protein in food. Deficiency causes megaloblastic anaemia.

Vitamin C Also known as ascorbic acid, is an essential water-soluble vitamin. It functions as co-factor for reactions requiring reduced copper or iron metallonzyme and as a protective anti-oxidant. Deficiency of vitamin C causes scurvy.

Vitamin D A group of fat-soluble, pro-hormone vitamin, the two major forms of which are vitamin D2 (or ergocalciferol) and vitamin D3 (or cholecalciferol). Vitamin D obtained from sun exposure, food and supplements is biologically inert and must undergo two hydroxylations in the body for activation. Vitamin D is essential for promoting calcium absorption in the gut and maintaining adequate serum calcium and phosphate concentrations to enable normal growth and mineralisation of bone and prevent hypocalcemic tetany. Deficiency causes rickets and osteomalacia. Vitamin D has other roles in human health, including modulation of neuromuscular and immune function, reduction of inflammation and modulation of many genes encoding proteins that regulate cell proliferation, differentiation and apoptosis.

Vitamin E Is the collective name for a group of fat-soluble compounds and exists in eight chemical forms (alpha-, beta-, gamma- and delta-tocopherol and alpha-, beta-, gamma- and delta-tocotrienol). It has pronounced antioxidant activities stopping the formation of reactive oxygen species when fat undergoes oxidation and help prevent or delay the chronic diseases associated with free radicals. Besides its antioxidant activities, vitamin E is involved in immune function, cell signalling, regulation of gene expression and other metabolic processes. Deficiency is very rare but can cause mild haemolytic anaemia in newborn infants.

Vitamin K A group of fat-soluble vitamins consisting of vitamin K1, which is also known as phylloquinone or phytomenadione (also called phytonadione), and vitamin K2 (menaquinone, menatetrenone). Vitamin K plays an important role in blood clotting. Deficiency is very rare but can cause bleeding diathesis.

Vitamin P A substance or mixture of substances obtained from various plant sources, identified as citrin or a mixture of bioflavonoids, thought to but not proven to be useful in reducing the extent of haemorrhage.

Vitiligo A chronic skin disease that causes loss of pigment, resulting in irregular pale patches of skin. It occurs when the melanocytes, cells responsible for skin pigmentation, die or are unable to function. Also called leucoderma.

Vitreoretinopathy See proliferative vitreoretinopathy.

VLA-4 Very late antigen-4, expressed by most leucocytes, but it is observed on neutrophils under special conditions.

VLDL See very-low-density lipoproteins.

Vomitive Substance that causes vomiting.

Vulnerary Wound healer, a substance used to heal wounds and promote tissue formation.

Vulva-vaginal erythema Abnormal redness and inflammation of the skin in the vagina.

Wart An infectious skin tumour caused by a viral infection.

Welt See wheal.

Wheal A firm, elevated swelling of the skin. Also called a weal or welt.

White fat White adipose tissue (WAT) in mammals, store of energy. *cf.* brown fat.

Whitlow Painful infection of the hand involving one or more fingers that typically affects the terminal phalanx.

Whooping cough Acute infectious disease usually in children caused by a *Bacillus* bacterium and accompanied by catarrh of the respiratory passages and repeated bouts of coughing.

Wnt signalling pathway Is a network of proteins involved in embryogenesis and cancer and also in normal physiological processes.

X-linked agammaglobulinemia Also known as X-linked hypogammaglobulinemia, XLA, Bruton-type agammaglobulinemia, Bruton syndrome, or sex-linked agammaglobulinemia; a rare x-linked genetic disorder that affects the body's ability to fight infection.

Xanthine oxidase A flavoprotein enzyme containing a molybdenum co-factor (Moco) and (Fe2S2) clusters, involved in purine metabolism. In humans, inhibition of xanthine oxidase reduces the production of uric acid and prevents hyperuricemia and gout.

Xanthones Unique class of biologically active phenol compounds with the molecular formula C13H8O2 possessing antioxidant properties, discovered in the mangosteen fruit.

Xenobiotics A chemical (as a drug, pesticide or carcinogen) that is foreign to a living organism.

Xenograft A surgical graft of tissue from one species to an unlike species.

Xerophthalmia A medical condition in which the eye fails to produce tears.

Xerostomia Dryness in the mouth due to lack of saliva production.

Yaws An infectious tropical infection of the skin, bones and joints caused by the spirochete bacterium *Treponema pertenue*, characterised by papules and pappiloma with subsequent deformation of the skins, bone and joints; also called framboesia.

yGCN5 A histone acetyl transferase (HAT) that plays a role in regulation of transciton, cell cycle progression and differentiation.

Yellow fever Is a viral disease that is transmitted to humans through the bite of infected mosquitoes. Illness ranges in severity from an influenza-like syndrome to severe hepatitis and haemorrhagic fever. Yellow fever virus (YFV) is maintained in nature by mosquito-borne transmission between non-human primates.

Zeaxanthin A common carotenoid, found naturally as coloured pigments in many fruit vegetables and leafy vegetables. It is important for good vision and is one of the two carotenoids contained within the retina of the eye. Within the central macula, zeaxanthin predominates, whereas in the peripheral retina, lutein predominates.

Zinc (Zn) Is an essential mineral for health. It is involved in numerous aspects of cellular metabolism:catalytic activity of enzymes, immune function, protein synthesis, wound healing, DNA synthesis and cell division. It also supports normal growth and development during pregnancy, childhood and adolescence and is required for proper sense of taste and smell. Dietary sources include beans, nuts, pumpkin seeds, sunflower seeds, whole wheat bread and animal sources.

ZK1 Krueppel-type zinc finger protein – bind DNA and, through this binding, regulate gene transcription.

ZO1 protein A high–molecular weight tight junction-associated protein.

Scientific Glossary

Abaxial Facing away from the axis, as of the surface of an organ.

Abortive Imperfectly formed.

Abscission Shedding of leaves, flowers or fruit following the formation of the abscission zone.

Acaulescent Lacking a stem or stem very much reduced.

Accrescent Increasing in size after flowering or with age.

Achene A dry, small, one-seeded, indehiscent one-seeded fruit formed from a superior ovary of one carpel as in sunflower.

Acid soil Soil that maintains a pH of less than 7.0.

Acidulous Acid or sour in taste.

Actinomorphic Having radial symmetry, capable of being divided into symmetrical halves by any plane, refers to a flower, calyx or corolla.

Aculeate Having sharp prickles.

Acuminate Tapering gradually to a sharp point.

Acute (Botany) tapering at an angle of less than 90° before terminating in a point as of leaf apex and base.

Adaxial Side closest to the stem axis.

Aldephous Having stamens united together by their filaments.

Adherent Touching without organic fusion as of floral parts of different whorls.

Adnate United with another unlike part as of stamens attached to petals.

Adpressed Lying close to another organ but not fused to it.

Adventitious Arising in abnormal positions, e.g. roots arising from the stem, branches or leaves, buds arising elsewhere than in the axils of leaves.

Adventive Not native to and not fully established in a new habitat or environment; locally or temporarily naturalised. e.g. an adventive weed.

Aestivation Refers to positional arrangement of the floral parts in the bud before it opens.

Akinete A thick-walled dormant cell derived from the enlargement of a vegetative cell. It serves as a survival structure.

Alfisols Soil with a clay-enriched subsoil and relatively high native fertility, having undergone only moderate leaching, containing aluminium, iron and with at least 35 % base saturation, meaning that calcium, magnesium and potassium are relatively abundant.

Alkaline soil Soil that maintains a pH above 7.0, usually containing large amounts of calcium, sodium and magnesium, and is less soluble than acidic soils.

Alkaloids Naturally occurring bitter, complex organic-chemical compounds containing basic nitrogen and oxygen atoms and having various pharmacological effects on humans and other animals.

Alternate Leaves or buds that are spaced along opposite sides of stem at different levels.

Allomorphic With a shape or form different from the typical.

Alluvial soil A fine-grained fertile soil deposited by water flowing over flood plains or in river beds.

Alluvium Soil or sediments deposited by a river or other running water.

Amplexicaul Clasping the stem as base of certain leaves.

Anatomising Interconnecting network as applied to leaf veins.

T.K. Lim, *Edible Medicinal and Non Medicinal Plants: Volume 9, Modified Stems, Roots, Bulbs*,
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Andisols Are soils formed in volcanic ash and containing high proportions of glass and amorphous colloidal materials.

Androdioecious With male flowers and bisexual flowers on separate plants.

Androecium Male parts of a flower; comprising the stamens of one flower.

Androgynophore A stalk bearing both the androecium and gynoecium above the perianth of the flower.

Androgynous With male and female flowers in distinct parts of the same inflorescence.

Andromonoecious Having male flowers and bisexual flowers on the same plant.

Angiosperm A division of seed plants with the ovules borne in an ovary.

Annual A plant which completes its life cycle within a year.

Annular Shaped like or forming a ring.

Annulus Circle or ring-like structure or marking; the portion of the corolla which forms a fleshy, raised ring.

Anthelate An open, paniculate cyme.

Anther The part of the stamen containing pollen sac which produces the pollen.

Antheriferous Containing anthers.

Anthesis The period between the opening of the bud and the onset of flower withering.

Anthocarp A false fruit consisting of the true fruit and the base of the perianth.

Anthocyanidins Are common plant pigments. They are the sugar-free counterparts of anthocyanins.

Anthocyanins A subgroup of antioxidant flavonoids, are glucosides of anthocyanidins. They occur as water-soluble vacuolar pigments that may appear red, purple or blue according to pH in plants.

Antipetala situated opposite petals.

Antisepala Situated opposite sepals.

Antrorse Directed forward upwards.

Apetalous Lacking petals as of flowers with no corolla.

Apical meristem Active growing point. A zone of cell division at the tip of the stem or the root.

Apically Towards the apex or tip of a structure.

Apiculate Ending abruptly in a short, sharp, small point.

Apiculum A short, pointed, flexible tip.

Apocarpous carpels separate in single individual pistils.

Apopetalous With separate petals, not united to other petals.

Aposepalous With separate sepals, not united to other sepals.

Appressed Pressed closely to another structure but not fused or united.

Aquatic A plant living in or on water for all or a considerable part of its life span.

Arachnoid (Botany) formed of or covered with long, delicate hairs or fibers.

Arborescent Resembling a tree; applied to non-woody plants attaining tree height and to shrubs tending to become tree-like in size.

Arbuscular mycorrhiza (AM) A type of mycorrhiza in which the fungus (of the phylum Glomeromycota) penetrates the cortical cells of the roots of a vascular plant and form unique structures such as arbuscules and vesicles. These fungi help plants to capture nutrients such as phosphorus and micronutrients from the soil.

Archegonium A flask-shaped female reproductive organ in mosses, ferns and other related plants.

Areolate With areolea.

Areole (Botany) a small, specialised, cushion-like area on a cactus from which hairs, glochids, spines, branches or flowers may arise; an irregular angular spces marked out on a surface e.g. fruit surface. *pl*. areolea.

Aril Specialised outgrowth from the funiculus (attachment point of the seed) (or hilum) that encloses or is attached to the seed. *adj*. arillate.

Arillode A false aril; an aril originating from the micropyle instead of from the funicle or chalaza of the ovule, e.g. mace of nutmeg.

Aristate Bristle-like part or appendage, e.g. awns of grains and grasses.

Aristulate Having a small, stiff, bristle-like part or appendage; a diminutive of aristate.

Articulate Jointed; usually breaking easily at the nodes or point of articulation into segments.

Ascending Arched upwards in the lower part and becoming erect in the upper part.

Ascospore Spore produced in the ascus in Ascomycete fungi.

Ascus Is the sexual spore-bearing cell produced in Ascomycete fungi. *pl*. asci.

Asperulous Refers to a rough surface with short, hard projections.

Attenuate Tapered or tapering gradually to a point.

Auricle An ear-like appendage that occurs at the base of some leaves or corolla.

Auriculate Having auricles.

Awn A hair-like or bristle-like appendage on a larger structure.

Axil Upper angle between a lateral organ, such as a leaf petiole and the stem that bears it.

Axile Situated along the central axis of an ovary having two or more locules, as in axile placentation.

Axillary Arising or growing in an axil.

Baccate Beery-like, pulpy or fleshy.

Barbate Bearded, having tufts of hairs.

Barbellae Short, stiff, hair-like bristles. *adj*. barbellate.

Bark Is the outermost layers of stems and roots of woody plants.

Basal Relating to, situated at, arising from or forming the base.

Basaltic soil Soil derived from basalt, a common extrusive volcanic rock.

Basidiospore A reproductive spore produced by Basidiomycete fungi.

Basidium A microscopic, spore-producing structure found on the hymenophore of fruiting bodies of Basidiomycete fungi.

Basifixed Attached by the base, as certain anthers are to their filaments.

Basionym The synonym of a scientific name that supplies the epithet for the correct name.

Beak A prominent apical projection, especially of a carpel or fruit. *adj*. beaked.

Bearded Having a tuft of hairs.

Berry A fleshy or pulpy indehiscent fruit from a single ovary with the seed(s) embedded in the fleshy tissue of the pericarp.

Biconvex Convex on both sides.

Biennial Completing the full cycle from germination to fruiting in more than one, but not more than 2 years.

Bifid Forked, divided into two parts.

Bifoliolate Having two leaflets.

Bilabiate Having two lips as of a corolla or calyx with segments fused into an upper and lower lip.

Bipinnate Twice pinnate; the primary leaflets being again divided into secondary leaflets.

Bipinnatisect Refers to a pinnately compound leaf, in which each leaflet is again divided into pinnae.

Biserrate Doubly serrate; with smaller regular, asymmetric teeth on the margins of larger teeth.

Bisexual Having both sexes, as in a flower bearing both stamens and pistil, hermaphrodite or perfect.

Biternate Twice ternate; with three pinnae each divided into three pinnules.

Blade Lamina; part of the leaf above the sheath or petiole.

Blotched See variegated.

Bole Main trunk of tree from the base to the first branch.

Brachyblast A short, axillary, densely crowded branchlet or shoot of limited growth, in which the internodes elongate little or not at all.

Bracket fungus Shelf fungus.

Bract A leaf-like structure, different in form from the foliage leaves, associated with an inflorescence or flower. *adj*. bracteate.

Bracteate Possessing bracts.

Bracteolate Having bracteoles.

Bracteole A small, secondary, bract-like structure borne singly or in a pair on the pedicel or calyx of a flower. *adj*. bracteolate.

Bran Hard outer layer of grain and comprises the aleurone and pericarp. It contains important antioxidant, vitamins and fibre.

Bristle A stiff hair.

Bulb A modified underground axis that is short and crowned by a mass of usually fleshy, imbricate scales. *adj*. bulbous.

Bulbil A small bulb or bulb-shaped body, especially one borne in the leaf axil or an inflorescence, and usually produced for asexual reproduction.

Bullate Puckered, blistered.

Burr Type of seed or fruit with short, stiff bristles or hooks or may refer to a deformed type of wood in which the grain has been misformed.

Bush Low, dense shrub without a pronounced trunk.

Buttress Supporting, projecting outgrowth from base of a tree trunk as in some Rhizophoraceae and Moraceae.

Caducous Shedding or falling early before maturity, refers to sepals and petals.

Caespitose Growing densely in tufts or clumps; having short, closely packed stems.

Calcareous Composed of or containing lime or limestone.

Calcrete A hardpan consisting gravel and sand cemented by calcium.

Callus A condition of thickened raised mass of hardened tissue on leaves or other plant parts often formed after an injury but sometimes a normal feature. A callus also can refer to an undifferentiated plant cell mass grown on a culture medium. *n*. callosity. *pl*. calli, callosities. *adj*. callose.

Calyptra The protective cap or hood covering the spore case of a moss or related plant.

Calyptrate Operculate, having a calyptra.

Calyx Outer floral whorl usually consisting of free sepals or fused sepals (calyx tube) and calyx lobes. It encloses the flower while it is still a bud. *adj*. calycine.

Calyx lobe One of the free upper parts of the calyx which may be present when the lower part is united into a tube.

Calyx tube The tubular fused part of the calyx, often cup shaped or bell shaped, when it is free from the corolla.

Campanulate Shaped like a bell refers to calyx or corolla.

Canaliculate Having groove or grooves.

Candelabriform Having the shape of a tall branched candle-stick.

Canescent Covered with short, fine whitish or grayish hairs or down.

Canopy Uppermost leafy stratum of a tree.

Cap See pileus.

Capitate Growing together in a head. Also means enlarged and globular at the tip.

Capitulum A flower head or inflorescence having a dense cluster of sessile or almost sessile, flowers or florets.

Capsule A dry, dehiscent fruit formed from two or more united carpels and dehiscing at maturity by sections called valves to release the seeds. *adj*. capsular.

Carinate Keeled.

Carpel A simple pistil consisting of ovary, ovules, style and stigma. *adj*. carpellary.

Carpogonium Female reproductive organ in red algae. *pl*. carpogonia.

Carpophore Part of the receptacle which is lengthened between the carpels as a central axis; any fruiting body or fruiting structure of a fungus.

Cartilaginous Sinewy, having a firm, tough, flexible texture (in respect of leaf margins).

Caruncle (Bot) fleshy structure attached to the seed of certain plants.

Caryopsis A simple dry, indehiscent fruit formed from a single ovary with the seed coat united with the ovary wall as in grasses and cereals.

Cataphyll A reduced or scarcely developed leaf at the start of a plant's life (i.e. cotyledons) or in the early stages of leaf development.

Catkin A slim, cylindrical, pendulous flower spike usually with unisexual flowers.

Caudate Having a narrow, tail-like appendage.

Caudex Thickened, usually underground base of the stem.

Caulescent Having a well developed aerial stem.

Cauliflory Botanical term referring to plants which flower and fruit from their main stems or woody trunks. *adj*. cauliflorus.

Cauline Borne on the aerial part of a stem.

Chaffy Having thin, membranous scales in the inflorescence as in the flower heads of the sunflower family.

Chalaza The basal region of the ovule where the stalk is attached.

Chamaephyte A low-growing perennial plant whose dormant overwintering buds are borne at or just above the surface of the ground.

Chartaceous Papery, of paper-like texture.

Chasmogamous Describing flowers in which pollination takes place while the flower is open.

Chatoyant Having a velvety sheen or lustre.

Chloroplast A chlorophyll-containing organelle (plastid) that gives the green colour to leaves and stems. Plastids harness light energy

that is used to fix carbon dioxide in the process called photosynthesis.

Chromoplast Plastid containing colored pigments apart from chlorophyll.

Chromosomes Thread-shaped structures that occur in pairs in the nucleus of a cell, containing the genetic information of living organisms.

Cilia Hairs along the margin of a leaf or corolla lobe.

Ciliate With a fringe of hairs on the margin as of the corolla lobes or leaf.

Ciliolate Minutely ciliate.

Cilium A straight, usually erect hair on a margin or ridge. *pl*. cilia.

Cincinnus A monochasial cyme in which the lateral branches arise alternately on opposite sides of the false axis.

Circinnate Spirally coiled, with the tip innermost.

Circumscissile Opening by a transverse line around the circumference as of a fruit.

Cladode The modified photosynthetic stem of a plant whose foliage leaves are much reduced or absent. *cf*. cladophyll, phyllode.

Cladophyll A photosynthetic branch or portion of a stem that resembles and functions as a leaf, like in asparagus. *cf*. cladode, phyllode.

Clamp connection In the Basidiomycetes fungi, a lateral connection or outgrowth formed between two adjoining cells of a hypha and arching over the septum between them.

Clavate Club shaped thickened at one end refer to fruit or other organs.

Claw The conspicuously narrowed basal part of a flat structure.

Clay A naturally occurring material composed primarily of fine-grained minerals like kaolinite, montmorrillonite-smectite or illite which exhibit plasticity through a variable range of water content and which can be hardened when dried and/or fired.

Clayey Resembling or containing a large proportion of clay.

Cleft Incised halfway down.

Cleistogamous Refers to a flower in which fertilisation occurs within the bud, i.e. without the flower opening. *cf*. chasmogamous.

Climber Growing more or less upwards by leaning or twining around another structure.

Clone All the plants reproduced, vegetatively, from a single parent thus having the same gentic make-up as the parent.

Coccus One of the sections of a distinctly lobed fruit which becomes separate at maturity; sometimes called a mericarp. *pl*. cocci.

Coenocarpium A fleshy, multiple pseudocarp formed from an inflorescence rather than a single flower.

Coherent Touching without organic fusion, referring to parts normally together, e.g. floral parts of the same whorl. *cf*. adherent, adnate, connate.

Collar Boundary between the above- and below ground parts of the plant axis.

Colliculate Having small elevations.

Column A structure formed by the united style, stigma and stamen(s) as in Asclepiadaceae and Orchidaceae.

Comose Tufted with hairs at the ends as of seeds.

Composite Having two types of florets as of the flowers in the sunflower family, Asteraceae.

Compost Organic matter (like leaves, mulch, manure, etc.) that breaks down in soil releasing its nutrients.

Compound Describe a leaf that is further divided into leaflets or pinnae or flower with more than a single floret.

Compressed Flattened in one plane.

Conceptacles Specialised cavities of marine algae that contain the reproductive organs.

Concolorous Uniformly coloured, as in upper and lower surfaces. *cf*. discolorous.

Conduplicate Folded together lengthwise.

Cone A reproductive structure composed of an axis (branch) bearing sterile bract-like organs and seed or pollen bearing structures. Applied to Gymnospermae, Lycopodiaceae, Casuarinaceae and also in some members of Proteaceae.

Conic Cone shaped, attached at the broader end.

Conic-capitate A cone-shaped head of flowers.

Connate Fused to another structure of the same kind. *cf*. adherent, adnate, coherent.

Connective The tissue separating two lobes of an anther.

Connivent Converging.
Conspecific Within or belonging to the same species.
Contorted Twisted.
Convolute Refers to an arrangement of petals in a bud where each has one side overlapping the adjacent petal.
Cordate Heart-shaped as of leaves.
Core Central part.
Coriaceous Leathery texture as of leaves.
Corm A short, swollen, fleshy, underground plant stem that serves as a food storage organ used by some plants to survive winter or other adverse conditions.
Cormel A miniature, new corm produced on a mature corm.
Corn silk The long, filamentous styles that grow as a silky tuft or tassel at the tip of an ear of corn.
Corolla The inner floral whorl of a flower, usually consisting of free petals or a petals fused forming a corolla tube and corolla lobes. *adj*. corolline.
Corona A crown-like section of the staminal column, usually with the inner and outer lobes as in the **Stapelieae**.
Coroniform Crown shaped, as in the pappus of Asteraceae.
Cortex The outer of the stem or root of a plant, bounded on the outside by the epidermis and on the inside by the endodermis containing undifferentiated cells.
Corymb A flat-topped, short, broad inflorescence, in which the flowers, through unequal pedicels, are in one horizontal plane and the youngest in the centre. *adj*. corymbose
Costa A thickened, linear ridge or the midrib of the pinna in ferns. *adj*. costate.
Costapalmate Having definite costa (midrib) unlike the typical palmate leaf, but the leaflets are arranged radially like in a palmate leaf.
Cotyledon The primary seed leaf within the embryo of a seed.
Cover crop Crop grown in between trees or in fields primarily to protect the soil from erosion, to improve soil fertility and to keep off weeds.
Crenate Round-toothed or scalloped as of leaf margins.
Crenulate Minutely crenate, very strongly scalloped.
Crested Frilled and ruffled edge.
Crispate Weakly undulating edge.
Crisped With a curled or twisted edge.
Cristate Having or forming a crest or crista.
Crozier Shaped like a shepherd's crook.
Crustaceous Like a crust; having a hard crust or shell.
Cucullate Having the shape of a cowl or hood, hooded.
Culm The main aerial stem of the Graminae (grasses, sedges, rushes and other monocots).
Culm sheath The plant casing (similar to a leaf) that protects the young bamboo shoot during growth, attached at each node of culm.
Cultigen Plant species or race known only in cultivation.
Cultivar Cultivated variety; an assemblage of cultivated individuals distinguished by any characters significant for the purposes of agriculture, forestry or horticulture and which, when reproduced, retains its distinguishing features.
Cuneate Wedge-shaped, obtriangular.
Cupular Cup-shaped, havin a cupule.
Cupule A small cup-shaped structure or organ, like the cup at the base of an acorn.
Cusp An elongated, usually rigid, acute point. *cf*. mucro.
Cuspidate Terminating in or tipped with a sharp firm point or cusp. *cf*. mucronate.
Cuspidulate Constricted into a minute cusp. *cf*. cuspidate.
Cyathiform In the form of a cup, a little widened at the top.
Cyathium A specialised type of inflorescence of plants in the genus Euphorbia and Chamaesyce in which the unisexual flowers are clustered together within a bract-like envelope. *pl*. cyathia.
Cylindric Tubular or rod shaped.
Cylindric-acuminate Elongated and tapering to a point.
Cymbiform Boat shaped, elongated and having the upper surface decidedly concave.
Cyme An inflorescence in which the lateral axis grows more strongly than the main axis with

the oldest flower in the centre or at the ends. *adj.* cymose.

Cymule A small cyme or one or a few flowers.

Cystidium A relatively large cell found on the hymenium of a Basidiomycete, for example, on the surface of a mushroom.

Cystocarp Fruitlike structure (sporocarp) developed after fertilisation in the red algae.

Deciduous Falling off or shedding at maturity or a specific season or stage of growth.

Decorticate To remove the bark, rind or husk from an organ; to strip off its bark; to come off as a skin.

Decompound As of a compound leaf; consisting of divisions that are themselves compound.

Decumbent Prostrate, laying or growing on the ground but with ascending tips. *cf.* ascending, procumbent.

Decurrent Having the leaf base tapering down to a narrow wing that extends to the stem.

Decussate Having paired organs with successive pairs at right angles to give four rows as of leaves.

Deflexed Bent downwards.

Degumming Removal of gum deposits (phosphatides, entrained oil and meal particles) from crude edible oils traditionally done with water. Water degumming process also remove hydrophilic substances such as sugars from the oil.

Dehisce To split open at maturity, as in a capsule.

Dehiscent Splitting open at maturity to release the contents. *cf.* indehiscent.

Deltate Triangular shape.

Deltoid Shaped like an equilateral triangle.

Dendritic Branching from a main stem or axis like the branches of a tree.

Dentate With sharp, rather coarse teeth perpendicular to the margin.

Denticulate Finely toothed.

Diageotropic The tendency of growing parts, such as roots, to grow at right angle to the line of gravity.

Diadelphous Having stamens in two bundles as in Papilionaceae flowers.

Dichasium A cymose inflorescence in which the branches are opposite and approximately equal. *pl*. dichasia. *adj.* dichasial.

Dichotomous Divided into two parts.

Dicotyledon Angiosperm with two cotyledons.

Didymous Arranged or occurring in pairs as of anthers, having two lobes.

Digitate Having digits or fingerlike projections.

Dikaryophyses Or dendrophydia, irregularly, strongly branched terminal hyphae in the Hymenomycetes (class of Basidiomyctes) fungi.

Dimorphic Having or occurring in two forms, as of stamens of two different lengths or a plant having two kinds of leaves.

Dioecious With male and female unisexual flowers on separate plants. *cf.* monoecious.

Diploid A condition in which the chromosomes in the nucleus of a cell exist as pairs, one set being derived from the female parent and the other from the male.

Diplobiontic life cycle Life cycle that exhibits alternation of generations, which features of spore-producing multicellular sporophytes and gamete-producing multicellular gametophytes. mitoses occur in both the diploid and haploid phases.

Diplontic life cycle Or gametic meiosis, wherein instead of immediately dividing meiotically to produce haploid cells, the zygote divides mitotically to produce a multicellular diploid individual or a group of more diploid cells.

Diplochory Seed dispersal involving two or more modes.

Dipterocarpous Trees of the family Dipterocarpaceae, with two-winged fruit found mainly in tropical lowland rainforest.

Disc (Botany) refers to the usually disc shaped receptacle of the flower head in Asteraceae; also the fleshy nectariferous organ usually between the stamens and ovary; also used for the enlarged style-end in Proteaceae.

Disc floret The central, tubular 4 or 5-toothed or lobed floret on the disc of an inflorescence, as of flower head of Asteraceae.

Disciform Flat and rounded in shaped. *cf.* discoid, radiate.

Discoid Resembling a disc; having a flat, circular form; disk-shaped *cf.* disciform, radiate.

Discolorous Having two colours, as of a leaf which has different colors on the two surfaces. *cf.* concolorous.

Disomic Having one or more chromosomes present twice but without the entire genome doubled.

Dispersal Dissemination of seeds.

Distal Site of any structure farthest from the point of attachment. *cf.* proximal.

Distichous Referring to two rows of upright leaves in the same plane.

Dithecous Having two thecae.

Divaricate Diverging at a wide angle.

Domatium A part of a plant (e.g. a leaf) that has been modified to provide protection for other organisms. *pl.* domatia.

Dormancy A resting period in the life of a plant during which growth slows or appears to stop.

Dorsal Referring to the back surface.

Dorsifixed Attached to the back as of anthers.

Drupaceous Resembling a drupe.

Drupe A fleshy fruit with a single seed enclosed in a hard shell (endocarp) which is tissue embedded in succulent tissue (mesocarp) surrounded by a thin outer skin (epicarp). *adj.* drupaceous.

Drupelet A small drupe.

Ebracteate Without bracts.

Echinate Bearing stiff, stout, bristly, prickly hairs.

Edaphic Refers to plant communities that are distinguished by soil conditions rather than by climate.

Eglandular Without glands. *cf.* glandular.

Elaioplasts A type of leucoplast that is specialised for the storage of lipids in plants.

Elaiosome Fleshy lipid-rich structures that are attached to the seeds of many plant species.

Ellipsoid A 3-dimensional shape; elliptic in outline.

Elliptic Having a 2-dimensional shape of an ellipse or flattened circle.

Elongate Extended, stretched out.

Emarginate Refers to leaf with a broad, shallow notch at the apex. *cf.* retuse.

Embryo (Botany) a minute rudimentary plant contained within a seed or an archegonium, composed of the embryonic axis (shoot end and root end).

Endemic Prevalent in or peculiar to a particular geographical locality or region.

Endocarp The hard innermost layer of the pericarp of many fruit.

Endosperm Tissue that surrounds and nourishes the embryo in the angiosperm seed. It contains starchy carbohydrates, proteins and small amounts of vitamins and minerals.

Endospermous Refers to seeds having an endosperm.

Ensiform Shaped like the blade of a sword, long and narrow with sharp edges and a pointed tip.

Endotrophic As of mycorrhiza obtaining nutrients from inside.

Ensilage The process of preserving green food for livestock in an undried condition in airtight conditions. Also called silaging.

Entire Having a smooth, continous margin without any incisions or teeth as of a leaf.

Entisols Soils that do not show any profile development other than an A horizon.

Ephemeral Transitory, short-lived.

Epicalyx A whorl of bracts, subtending and resembling a calyx.

Epicarp Outermost layer of the pericarp of a fruit.

Epicormic Attached to the corm.

Epicotyl The upper portion of the embryonic axis, above the cotyledons and below the first true leaves.

Epigeal Above grounds with cotyledons raised above ground.

Epiparasite An organism parasitic on another that parasitises a third.

Epipetalous Borne on the petals, as of stamens.

Epiphyte A plant growing on, but not parasitic on, another plant, deriving its moisture and nutrients from the air and rain e.g. some Orchidaceae. *adj.* epiphytic.

Epithet Name.

Equitant In a loose fan pattern.

Erect Upright, vertical.

Essential oils Volatile products obtained from a natural source; refers to volatile products obtained by steam or water distillation in a strict sense.

Etiolation To cause (a plant) to develop without chlorophyll by preventing exposure to sunlight.

Eutrophic Having waters rich in mineral and organic nutrients that promote a proliferation

of plant life, especially algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms.

Excentric Off the true centre.

Excrescence Abnormal outgrowth.

Excurrent Projecting beyond the tip, as the midrib of a leaf or bract.

Exserted Sticking out, protruding beyond some enclosing organ, as of stamens which project beyond the corolla or perianth.

Exstipulate Without stipules. *cf.* stipulate.

Extra-floral Outside the flower.

Extrose Turned outwards or away from the axis as of anthers. *cf.* introrse, latrorse.

Falcate Sickle-shaped, crescent-shaped.

Fascicle A cluster or bundle of stems, flowers, stamens. *adj.* fasciculate.

Fasciclode Staminode bundles.

Fastigiate A tree in which the branches grow almost vertically.

Ferrosols Soils with an iron oxide content of greater than 5 %.

Ferruginous Rust coloured, reddish-brown.

Fertile Having functional sexual parts which are capable of fertilisation and seed production. *cf.* sterile.

Filament The stalk of a stamen supporting and subtending the anther.

Filiform Having the form of or resembling a thread or filament.

Fimbriate Fringed.

Fixed oils Non volatile oils, triglycerides of fatty acids.

Flaccid Limp and weak.

Flag leaf The uppermost leaf on the stem.

Flaky In the shape of flakes or scales.

Flexuous Zig-zagging, sinuous, bending, as of a stem.

Floccose Covered with tufts of soft woolly hairs.

Floral tube A flower tube usually formed by the basal fusion of the perianth and stamens.

Floret One of the small individual flowers of sunflower family or the reduced flower of the grasses, including the lemma and palea.

Flower The sexual reproductive organ of flowering plants, typically consisting of gynoecium, androecium and perianth or calyx and/or corolla and the axis bearing these parts.

Fluted As of a trunk with grooves and folds.

Fodder Plant material, fresh or dried fed to animals.

Foliaceous Leaf-like.

Foliage Leaves of the plant.

Foliar Pertaining to a leaf.

Foliolate Pertaining to leaflets, used with a number prefix to denote the number of leaflets.

Foliose Leaf-like.

Follicle (Botany) a dry fruit, derived from a single carpel and dehiscing along one suture.

Forb Any herb that is not grass or grass-like.

Foveolate Surface pitted with shallow depressions.

Free central placentation The arrangement of ovules on a central column that is not connected to the ovary wall by partitions, as in the ovaries of the carnation and primrose.

Frond The leaf of a fern or cycad.

Fruit Ripened ovary with adnate parts.

Frutescent Shrubby.

Fugacious Shedding off early.

Fulvous Yellow, tawny.

Funiculus (Botany) short stalk which attaches the ovule to the ovary wall.

Fuscescent Dusky.

Fusiform A 3-dimensional shape; spindle shaped, i.e. broad in the centre and tapering at both ends thick, but tapering at both ends.

Gall-flowers Short styled flowers that do not develop into a fruit but are adapted for the development of a specific wasp within the fruit e.g. in the fig.

Gamete A reproductive cell that fuses with another gamete to form a zygote. Gametes are haploid, (they contain half the normal (diploid) number of chromosomes); thus when two fuse, the diploid number is restored.

Gametophyte The gamete-producing phase in a plant characterised by alternation of generations.

Gamosepalous With sepals united or partially united.

Genome Complete set of genetic material of an organism.

Geniculate Bent like a knee, refer to awns and filaments.

Geocarpic Where the fruit are pushed into the soil by the gynophore and mature.

Geophyte A plant that stores food in an underground storage organ e.g. a tuber, bulb or rhizome and has subterranean buds which form aerial growth.

Geotextile Are permeable fabrics which, when used in association with soil, have the ability to separate, filter, reinforce, protect or drain.

Germ Of cereal is the embryo of the seed or kernel. It contains vitamins B, E, folic acid, some protein, minerals and polyunsaturated fats.

Glabrescent Becoming glabrous.

Glabrous Smooth, hairless without pubescence.

Gland A secretory organ, e.g. a nectary, extra-floral nectary or a gland tipped, hair-like or wart-like organ. *adj.* glandular. *cf.* eglandular.

Glaucous Pale blue-green in colour, covered with a whitish bloom that rubs off readily.

Gley soils A hydric soil which exhibits a greenish-blue-grey soil color due to wetland conditions.

Globose Spherical in shape.

Globular A three-dimensional shape; spherical or orbicular; circular in outline.

Glochids Tiny, finely barbed hair-like spines found on the areoles of some cacti and other plants.

Glochidiate Having glochids.

Glochidote Plant having gkochids.

Glume One of the two small, sterile bracts at the base of the grass spikelet, called the lower and upper glumes, due to their position on the rachilla. Also used in Apiaceae, Cyperaceae for the very small bracts on the spikelet in which each flower is subtended by one floral glume. *adj.* glumaceous.

Grits Consist of coarsely ground corn or sometimes alkali-treated corn.

Groats Hulled, whole grains of various cereals, such as oats, wheat, barley or buckwheat, it includes the cereal germ, fiber-rich bran portion and endosperm of the grain.

Guttation The appearance of drops of xylem sap on the tips or edges of leaves of some vascular plants, such as grasses and bamboos.

Guttule Small droplet.

Gymnosperm A group of spermatophyte seed-bearing plants with ovules on scales, which are usually arranged in cone-like structures and not borne in an ovary. *cf.* angiosperm.

Gynoecium The female organ of a flower; a collective term for the pistil, carpel or carpels.

Gynomonoecious Having female flowers and bisexual flowers on the same plant. *cf.* andromonoecious.

Gynophore Stalk that bears the pistil/carpel.

Habit The general growth form of a plant, comprising its size, shape, texture and stem orientation, the locality in which the plant grows.

Halophyte A plant adapted to living in highly saline habitats. Also, a plant that accumulates high concentrations of salt in its tissues. *adj.* halophytic.

Hapaxanthic Refer to palms which flowers only once and then dies. c.f. pleonanthic.

Haploid Condition where nucleus or cell has a single set of unpaired chromosomes, the haploid number is designated as *n*.

Haplontic life cycle Or zygotic meiosis wherein meiosis of a zygote immediately after karyogamy, produces haploid cells which produces more or larger haploid cells ending its diploid phase.

Hastate Having the shape of an arrowhead but with the basal lobes pointing outward at right angles as of a leaf.

Hastula A piece of plant material at the junction of the petiole and the leaf blade; the hastula can be found on the top of the leaf, adaxial or the bottom, abaxial or both sides.

Heartwood Wood from the inner portion of a tree.

Heliophilous Sun-loving, tolerates high level of sunlight.

Heliotropic Growing towards sunlight.

Herb A plant which is non-woody or woody at the base only, the above ground stems usually being ephemeral. *adj.* herbaceous.

Herbaceous Resembling a herb, having a habit of a herb.

Hermaphrodite Bisexual, bearing flowers with both androecium and gynoecium in the same flower. *adj.* hermaphroditic.

Heterocyst A differentiated cyanobacterial cell that carries out nitrogen fixation.

Heterogamous Bearing separate male and female flowers, bisexual and female flowers

or florets in an inflorescence or flower head, e.g. some Asteraceae in which the ray florets may be neuter or unisexual and the disk florets may be bisexual. *cf.* homogamous.

Heteromorphous Having two or more distinct forms. *cf.* homomorphous.

Heterophyllous Having leaves of different form.

Heterosporous Producing spores of two sizes, the larger giving rise to megagametophytes (female), the smaller giving rise to microgametophytes (male). Refer to the ferns and fern allies. *cf.* homosporous.

Heterostylous Having styles of two different lengths or forms.

Heterostyly The condition in which flowers on polymorphous plants have styles of different lengths, therby facilting cross-pollination.

Hilar Of or relating to a hilum.

Hilum The scar on a seed, indicating the point of attachment to the funiculus.

Hirsute Bearing long coarse hairs.

Hispid Bearing stiff, short, rough hairs or bristles.

Hispidulous Minutely hispid.

Histosol Soil comprising primarily of organic materials, having 40 cm or more of organic soil material in the upper 80 cm.

Hoary Covered with a greyish layer of very short, closely interwoven hairs.

Holdfast An organ or structure of attachment, especially the basal, root-like formation by which certain seaweeds or other algae are attached to a substrate.

Holocarpic Having the entire thallus developed into a fruiting body or sporangium.

Homochromous Having all the florets of the same colour in the same flower head *cf.* heterochromous.

Homogamous Bearing flowers or florets that do not differ sexually *cf.* heterogamous.

Homogenous endosperm Endosperm with even surface that lacks invaginations or infoldings of the surrounding tissue.

Homogonium A part of a filament of a cyanobacterium that detaches and grows by cell division into a new filament. *pl.* homogonia.

Homomorphous Uniform, with only one form. *cf.* heteromorphous.

Homosporous Producing one kind of spores. Refer to the ferns and fern allies. *cf.* heterosporous.

Hurd fibre Long pith fibre of the stem.

Hyaline Colourless, almost transparent.

Hybrid The first generation progeny of the sexual union of plants belonging to different taxa.

Hybridisation The crossing of individuals from different species or taxa.

Hydathode A type of secretory tissue in leaves, usually of Angiosperms, that secretes water through pores in the epidermis or margin of the leaf.

Hydrophilous Water loving; requiring water in order to be fertilised, referring to many aquatic plants.

Hygrochastic Applied to plants in which the opening of the fruit is caused by the absorption of water.

Hygrophilous Living in water or moist places.

Hymenial cystidia The cells of the hymenium develop into basidia or asci, while in others some cells develop into sterile cells called cystidia.

Hymenium Spore-bearing layer of cells in certain fungi containing asci (Ascomycetes) or basidia (Basidiomycetes).

Hypanthium Cup-like receptacles of some dicotyledonous flowers formed by the fusion of the calyx, corolla and androecium that surrounds the ovary which bears the sepals, petals and stamens. Adj. relating to or of the nature of a hypanthium.

Hypha Is a long, branching filamentous cell of a fungus and also of unrelated Actinobacteria. *pl.* hyphae.

Hypocotyl The portion of the stem below the cotyledons.

Hypodermis The cell layer beneath the epidermis of the pericarp.

Hypogeal Below ground as of germination of seed.

Hysteresis Refers to systems that may exhibit path dependence.

Imbricate Closely packed and overlapping. *cf.* valvate.

Imparipinnate Pinnately compound with a single terminal leaflet and hence with an odd number of leaflets. *cf.* paripinnate.

Inceptisols Old soils that have no accumulation of clays, iron, aluminium or organic matter.

Incised Cut jaggedly with very deep teeth.

Included Referring to stamens which do not project beyond the corolla or to valves which do not extend beyond the rim of a capsular fruit. *cf.* exserted.

Incurved Curved inwards; curved towards the base or apex.

Indefinite Numerous and variable in number.

Indehiscent Not opening or splitting to release the contents at maturity as of fruit. *cf.* dehiscent.

Indumentum Covering of fine hairs or bristles commonly found on external parts of plants.

Indurate To become hard, often the hardening developed only at maturity.

Indusium An enclosing membrane, covering the sorus of a fern. Also used for the modified style end or pollen-cup of some Goodeniaceae (including Brunoniaceae). *adj.* indusiate.

Inferior Said of an ovary or fruit that has sepals, petals and stamens above the ovary. *cf.* superior.

Inflated Enlarged and hollow except in the case of a fruit which may contain a seed. *cf.* swollen.

Inflexed Bent or curved inward or downward, as petals or sepals.

Inflorescence A flower cluster or the arrangement of flowers in relation to the axis and to each other on a plant.

Infrafoliar Located below the leaves.

Infraspecific Referring to any taxon below the species rank.

Infructescence The fruiting stage of an inflorescence.

Infundibulum Funnel shaped cavity or structure.

Inrolled Curved inwards.

Integuments Two distinct tissue layers that surround the nucellus of the ovule, forming the testa or seed coat when mature.

Intercalary Of growth, between the apex and the base; of cells, spores, etc., between two cells.

Interfoliar Inter leaf.

Internode Portion of the stem, culm, branch or rhizome between two nodes or points of attachment of the leaves.

Interpetiolar As of stipules positioned between petioles of opposite leaves.

Intrastaminal Within the stamens.

Intricate Entangled, complex.

Introduced Not indigenous; not native to the area in which it now occurs.

Introrse Turned inwards or towards the axis or pistil as of anthers. *cf.* extrorse, latrorse.

Involucre A whorl of bracts or leaves that surround one to many flowers or an entire inflorescence.

Involute Having the margins rolled inwards, referring to a leaf or other flat organ.

Jugate Of a pinnate leaf; having leaflets in pairs.

Juvenile Young or immature, used here for leaves formed on a young plant which are different in morphology from those formed on an older plant.

Keel A longitudinal ridge at the back of the leaf. Also, the two lower fused petals of a 'pea' flower in the Papilionaceae, which form a boat-like structure around the stamens and styles, also called carina. *adj.* keeled. *cf.* standard, wing.

Labellum The modified lowest of the three petals forming the corolla of an orchid, usually larger than the other two petals and often spurred.

Lacerate Irregularly cleft.

Laciniate Fringed; having a fringe of slender, narrow, pointed lobes cut into narrow lobes.

Lamella A gill-shaped structure: fine sheets of material held adjacent to one another.

Lamina The blade of the leaf or frond.

Lanate Wooly, covered with long hairs which are loosely curled together like wool.

Lanceolate Lance-shaped in outline, tapering from a broad base to the apex.

Landrace Plants adapted to the natural environment in which they grow, developing naturally with minimal assistance or guidance from humans and usually possess more diverse phenotypes and genotypes. They have not been improved by formal breeding programs.

Laterite Reddish–coloured soils rich in iron oxide, formed by weathering of rocks under oxidising and leaching conditions, commonly found in tropical and subtropical regions. *adj.* lateritic.

Latex A milky, clear or sometimes coloured sap of diverse composition exuded by some plants.

Latrorse Turned sideways, i.e. not towards or away from the axis as of anthers dehiscing longitudinally on the side. *cf.* extrorse, introse.

Lax Loose or limp, not densely arranged or crowded.

Leaflet One of the ultimate segments of a compound leaf.

Lectotype A specimen chosen after the original description to be the type.

Lemma The lower of two bracts (scales) of a grass floret, usually enclosing the palea, lodicules, stamens and ovary.

Lenticel Is a lens shaped opening that allows gases to be exchanged between air and the inner tissues of a plant, commonly found on young bark, or the surface of the fruit.

Lenticellate Dotted with lenticels.

Lenticular Shaped like a biconvex lens. *cf.* lentiform.

Lentiform Shaped like a biconvex lens, *cf.* lenticular.

Leptomorphic Temperate, running bamboo rhizome; usually thinner then the culms they support and the internodes are long and hollow.

Liane A woody climbing or twining plant.

Ligneous Woody.

Lignotuber A woody, usually underground, tuberous rootstock often giving rise to numerous aerial stems.

Ligulate Small and tongue shaped or with a little tongue shaped appendage or ligule, star shaped as of florets of Asteraceae.

Ligule A strap-shaped corolla in the flowers of Asteraceae; also a thin membranous outgrowth from the inner junction of the grass leaf sheath and blade. *cf.* ligulate.

Limb The expanded portion of the calyx tube or the corolla tube or the large branch of a tree.

Linear A 2-dimensional shape, narrow with nearly parallel sides.

Linguiform Tongue shaped *cf.* ligulate.

Lipotubuloids Are cytoplasmic domains containing aggragates of lipid bodies surrounded by a network of microtubules, which join one lipid body with the others.

Lithosol A kind of shallow soils lacking well-defined horizons and composed of imperfectly weathered fragments of rock.

Littoral Of or on a shore, especially seashore.

Loam A type of soil mad up of sand, silt and clay in relative concentration of 40-40-20 % respectively.

Lobed Divided but not to the base.

Loculicidal Opening into the cells, when a ripe capsule splits along the back.

Loculus Cavity or chamber of an ovary. *pl.* loculi.

Lodicules Two small structures below the ovary which, at flowering, swell up and force open the enclosing bracts, exposing the stamens and carpel.

Lorate Strap-shaped with obtuse tip.

Lyrate Pinnately lobed, with a large terminal lobe and smaller laterals ones which become progressively smaller towards the base.

Macronutrients Chemical elements which are needed in large quantities for growth and development by plants and include nitrogen, phopshorus, potassium and magnesium.

Maculate Spotted.

Mallee A growth habit in which several to many woody stems arise separately from a lignotuber; usually applied to certain low-growing species of *Eucalyptus.*

Mangrove A distinctive vegetation type of trees and shrubs with modified roots, often viviparous, occupying the saline coastal habitats that are subject to periodic tidal inundation.

Marcescent Withering or to decay without falling off.

Margin The edge of the leaf blade.

Medulla The pith in the stems or roots of certain plants; or the central portion of a thallus in certain lichens.

Megasporangium The sporangium containing megaspores in fern and fern allies. *cf.* microsporangium.

Megaspore The large spore which may develop into the female gametophyte in heterosporous ferns and fern allies. *cf.* microspore.

Megasporophyll A leaflike structure that bears megasporangia.

Megastrobilus Female cone, seed cone or ovulate cone, contains ovules within which, when

fertilised by pollen, become seeds. The female cone structure varies more markedly between the different conifer families.

Meiosis The process of cell division that results in the formation of haploid cells from diploid cells to produce gametes.

Mericarp A 1-seeded portion of an initially syncarpous fruit (schizocarp) which splits apart at maturity. *cf.* coccus.

Meristem The region of active cell division in plants, from which permanent tissue is derived. *adj.* meristematic.

Merous Used with a number prefix to denote the basic number of the three outer floral whorls, e.g. a 5-merous flower may have five sepals, ten petals and 15 stamens.

Mesic Moderately wet.

Mesocarp The middle layer of the fruit wall derived from the middle layer of the carpel wall. *cf.* endocarp, exocarp, pericarp.

Mesophytes Terrestrial plants which are adapted to neither a particularly dry nor particularly wet environment.

Micropyle The small opening in a plant ovule through which the pollen tube passes in order to effect fertilisation.

Microsporangium The sporangium containing microspores in petridophyes. *cf.* megasporangium.

Microspore A small spore which gives rise to the male gametophyte in heterosporous pteridophytes. Also for a pollen grain. *cf.* megaspore.

Midvein The main vascular supply of a simple leaf blade or lamina. Also called mid-rib.

Mitosis Is a process of cell division which results in the production of two daughter cells from a single parent cell.

Mollisols Soils with deep, high organic matter, nutrient-enriched surface soil (A horizon), typically between 60 and 80 cm thick.

Monadelphous Applied to stamens united by their filaments into a single bundle.

Monocarpic Refer to plants that flower, set seeds and then die.

Monochasial A cyme having a single flower on each axis.

Monocotyledon Angiopsrem having one cotyledon.

Monoecious Having both male and female unisexual flowers on the same individual plant. *cf.* dioecious.

Monoembryonic seed The seed contains only one embryo, a true sexual (zygotic) embryo. polyembryonic seed.

Monolete A spore that has a simple linear scar.

Monopodial With a main terminal growing point producing many lateral branches progressively. *cf.* sympodial.

Monostichous Forming one row.

Monotypic Of a genus with one species or a family with one genus; in general, applied to any taxon with only one immediately subordinate taxon.

Montane Refers to highland areas located below the subalpine zone.

Mucilage A soft, moist, viscous, sticky secretion. *adj.* mucilaginous.

Mucous (Botany) slimy.

Mucro A sharp, pointed part or organ, especially a sharp terminal point, as of a leaf.

Mucronate Ending with a short, sharp tip or mucro, resembling a spine. *cf.* cuspidate, muticous.

Mucronulate With a very small mucro; a diminutive of mucronate.

Mulch Protective cover of plant (organic) or non-plant material placed over the soil, primarily to modify and improve the effects of the local microclimate and to control weeds.

Multiple fruit A fruit that is formed from a cluster of flowers.

Muricate Covered with numerous short hard outgrowths. *cf.* papillose.

Muriculate With numerous minute hard outgrowths; a diminutive of muricate.

Muticous Blunt, lacking a sharp point. *cf.* mucronate.

MYB proteins Are a superfamily of transcription factors that play regulatory roles in developmental processes and defense responses in plants.

Mycorrhiza The mutualistic symbiosis (non-pathogenic association) between soil-borne fungi with the roots of higher plants.

Mycorrhiza (vesicular arbuscular) Endomycorrhiza living in the roots of higher plants producing inter-and intracellular fungal

growth in root cortex and forming specific fungal structures, referred to as vesicles and arbuscles. *abbrev.* VAM.

Myrmecochory Seed dispersal by ants.

Native A plant indigenous to the locality or region.

Naviculate Boat-shaped.

Necrotic Applied to dead tissue.

Nectariferous Having one or more nectaries.

Nectary A nectar-secretory gland; commonly in a flower, sometimes on leaves, fronds or stems.

Nervation Venation, a pattern of veins or nerves as of leaf.

Nixtamalisation Refers to a process for the preparation of maize (corn) or other grain, in which the grains are soaked and cooked in an alkaline solution, usually limewater, and hulled.

Node The joint between segments of a culm, stem, branch or rhizome; the point of the stem that gives rise to the leaf and bud.

Nodule A small knoblike outgrowth, as those found on the roots of many leguminous, that containing *Rhizobium* bacteria which fixes nitrogen in the soil.

Nom. ambig. Nomen ambiguum (Latin) ambiguous name used in different senses which has become a long-persistent source of error.

Nom. cons. Nomen nonservandum (Latin) name conserved in International Code of Botanical Nomenclature.

Nom. dub. Nomen dubium (Latin) an invalid proposed taxonomic name because it is not accompanied by a definition or description of the taxon to which it applies.

Nom. illeg. Nomen illegitimum (Latin) illegitimate taxon deemed as superfluous at its time of publication either because the taxon to which it was applied already has a name or because the name has already been applied to another plant.

Nom. invalid. Nomen invalidum (Latin) invalid name according to International Code of Botanical Nomenclature.

Nom. nud. Nomen nudum (Latin) the name of a taxon which has never been validated by a description.

Nom. rej. Nomen rejiciendum (Latin) name rejected in International Code of Botanical Nomenclature.

Notho- (Subsp. or var.) prefix to the rank of a hybrid taxon below the rank of species.

Nucellus Central portion of an ovule in which the embryo sac develops.

Nucellar embryony A form of seed reproduction in which the nucellar tissue which surrounds the embryo sac can produce additional embryos (polyembryony) which are genetically identical to the parent plant. This is found in many citrus species and in mango.

Nut A dry indehiscent 1-celled fruit with a hard pericarp.

Nutlet A small. 1-seeded, indehiscent lobe of a divided fruit.

Ob- Prefix meaning inverse or opposite to.

Obconic A 3-dimensional shape; inversely conic; cone shaped, conic with the vertex pointing downward.

Obcordate Inversely cordate, broad and notched at the tip; heart shaped but attached at the pointed end.

Obdeltate Inversely deltate; deltate with the broadest part at the apex.

Oblanceolate Inversely lanceolate, lance-shaped but broadest above the middle and tapering toward the base as of leaf.

Oblate Having the shape of a spheroid with the equatorial diameter greater than the polar diameter; being flattened at the poles.

Oblong Longer than broad with sides nearly parallel to each other.

Obovate Inversely ovate, broadest above the middle.

Obpyramidal Resembling a 4-sided pyramid attached at the apex with the square base facing away from the attachment.

Obpyriform Inversely pyriform, resembling a pear which is attached at the narrower end. *cf.* pyriform.

Obspathulate Inversely spathulate; resembling a spoon but attached at the broadest end. *cf.* spathulate.

Obtriangular Inversely triangular; triangular but attached at the apex. *cf.* triangular.

Obtrullate Inversely trullate; resembling a trowel blade with the broadest axis above the middle. *cf.* trullate.

Obtuse With a blunt or rounded tip, the converging edges separated by an angle greater than 90°.

-oid Suffix denoting a 3-dimensional shape, e.g. spheroid.

Ochraceous A dull yellow color.

Ocreate Having a tube-like covering around some stems, formed of the united stipules; sheathed.

Oleaginous Oily.

Oligotrophic Lacking in plant nutrients and having a large amount of dissolved oxygen throughout.

Operculum A lid or cover that becomes detached at maturity by abscission, e.g. in *Eucalyptus*, also a cap or lid covering the bud and formed by fusion or cohesion of sepals and/or petals. *adj.* operculate.

Opposite Describing leaves or other organs which are borne at the same level but on opposite sides of the stem. *cf.* alternate.

Orbicular Of circular outline, disc-like.

Order A taxonomic rank between class and family used in the classification of organisms, i.e. a group of families believed to be closely related.

Orifice An opening or aperture.

Organosols Soils not regularly inundated by marine waters and containing a specific thickness of organic materials within the upper part of the profile.

Orth. Var. Orthographic variant, i.e. an incorrect alternate spelling of a name.

Ovary The female part of the pistil of a flower which contains the ovules (immature seeds).

Ovate Egg-shaped, usually with reference to two dimensions.

Ovoid Egg-shaped, usually with reference to three dimensions.

Ovule The young, immature seed in the ovary which becomes a seed after fertilisation. *adj.* ovular.

Ovulode A sterile reduced ovule borne on the placenta, commonly occurring in Myrtaceae.

Oxisols Refer to ferralsols.

Pachymorphic Describes the short, thick rhizomes of clumping bamboos with short, thick and solid inter-node (except the bud-bearing internodes, which are more elongated). *cf.* sympodial.

Palate (Botany) a raised appendage on the lower lip of a corolla which partially or completely closes the throat.

Palea The upper of the two membraneous bracts of a grass floret, usually enclosing the lodicules, stamens and ovary. *pl.* paleae. *adj.* paleal. *cf.* lemma.

Paleate Having glumes.

Palm heart Refers to soft, tender inner core and growing bud of certain palm trees which are eaten as vegetables. Also called heart of palm, palmito, burglar's thigh, chonta or swamp cabbage.

Palmate Describing a leaf which is divided into several lobes or leaflets which arise from the same point. *adj.* palmately.

Palmito See palm heart.

Palustrial Paludal, swampy, marshy.

Palustrine Marshy, swampy.

Palustrine herb Vegetation that is rooted below water but grows above the surface in wetland system.

Panduriform Fiddle shaped, usually with reference to two dimensions.

Panicle A compound, indeterminate, racemose inflorescence in which the main axis bears lateral racemes or spikes. *adj.* paniculate.

Pantropical Distributed through-out the tropics.

Papilionaceous Butterfly-like, said of the pea flower or flowers of Papilionaceae, flowers which are zygomorphic with imbricate petals, one broad upper one, two narrower lateral ones and two narrower lower ones.

Papilla A small, superficial protuberance on the surface of an organ being an outgrowth of one epidermal cell. *pl.* papillae. *adj.* papillose.

Papillate Having papillae.

Papillose Covered with papillae.

Pappus A tuft (or ring) of hairs, bristles or scales borne above the ovary and outside the corolla as in Asteraceae often persisting as a tuft of hairs on a fruit. *adj.* pappose.

Papyraceous Resembling parchment of paper.

Parenchyma Undifferentiated plant tissue composed of more or less uniform cells.

Parietal Describes the attachment of ovules to the outer walls of the ovaries.

Paripinnate Pinnate with an even number of leaflets and without a terminal leaflet. *cf.* imparipinnate.

-partite Divided almost to the base into segments, the number of segments written as a prefix.

Patelliform Shaped like a limpet shell; cap-shaped and without whorls.

Patent Diverging from the axis almost at right angles.

Peat Is an accumulation of partially decayed vegetation matter.

Pectin A group of water-soluble colloidal carbohydrates of high molecular weight found in certain ripe fruit.

Pectinate Pinnatifid with narrow segments resembling the teeth of a comb.

Pedicel The stalk of the flower or stalk of a spikelet in Poaceae. *adj.* pedicellate.

Pedicellate Having pedicel.

Peduncle A stalk supporting an inflorescence. *adj.* pedunculate.

Pellucid Allowing the passage of light; transparent or translucent.

Pellucid-dotted Copiously dotted with immersed, pellucid, resinous glands.

Peltate With the petiole attached to the lower surface of the leaf blade.

Pendant Hanging down.

Pendulous Drooping, as of ovules.

Penniveined or penni-nerved Pinnately veined.

Pentamerous In five parts.

Perennial A plant that completes it life cycle or lives for more than two years. *cf.* annual, biennial.

Perfoliate A leaf with the basal lobes united around–and apparently pierced by–the stem.

Pergamentaceous Parchment-like.

Perianth The two outer floral whorls of the Angiosperm flower; commonly used when the calyx and the corolla are not readily distinguishable (as in monocotyledons).

Pericarp (Botany). The wall of a ripened ovary; fruit wall composed of the exocarp, mesocarp and endocarp.

Persistent Remaining attached; not falling off. *cf.* caduceus.

Petal Free segment of the corolla. *adj.* petaline. *cf.* lobe.

Petiolar Relating to the petiole.

Petiolate Having petiole.

Petiole Leaf stalk. *adj.* petiolate.

Petiolulate Supported by its own petiolule.

Petiolule The stalk of a leaflet in a compound leaf. *adj*. petiolulate.

pH Is a measure of the acidity or basicity of a solution. It is defined as the cologarithm of the activity of dissolved hydrogen ions (H+).

Phenology The study of periodic plant life cycle events as influenced by seasonal and interannual variations in climate.

Phyllary A bract of the involucre of a composite plant, term for one of the scale-like bracts beneath the flower-head in Asteraceae.

Phylloclade A flattened, photosynthetic branch or stem that resembles or performs the function of a leaf, with the true leaves represented by scales.

Phyllode A petiole that function as a leaf. *adj.* phyllodineous. *cf.* cladode.

Phyllopodia Refer to the reduced, scale-like leaves found on the outermost portion of the corm where they seem to persist longer than typical sporophylls as in the fern Isoetes.

Phytoremediation Describes the treatment of environmental problems (bioremediation) through the use of plants which mitigate the environmental problem without the need to excavate the contaminant material and dispose of it elsewhere.

Pileus (Botany) cap of mushroom.

Piliferous (Botany) bearing or producing hairs, as of an organ with the apex having long, hair-like extensions.

Pilose Covered with fine soft hairs.

Pinna A primary division of the blade of a compound leaf or frond. *pl.* pinnae.

Pinnate Bearing leaflets on each side of a central axis of a compound leaf; divided into pinnae.

Pinnatifid, pinnatilobed A pinnate leaf parted approximately halfway to midrib; when divided to almost to the mid rib described as deeply pinnatifid or pinnatisect.

Pinnatisect Lobed or divided almost to the midrib.

Pinnule A leaflet of a bipinnate compound leaf.

Pistil Female part of the flower comprising the ovary, style and stigma.

Pistillate Having one or more pistils; having pistils but no stamens.

Placenta The region within the ovary to which ovules are attached. *pl.* placentae.

Placentation The arrangement of the placentae and ovules in the ovary.

Plano- A prefix meaning level or flat.

Pleonanthic Refer to palms in which the stem does not die after flowering.

Plicate Folded like a fan.

Plumose Feather-like, with fine hairs arising laterally from a central axis; feathery.

Pneumatophore Modified root which allows gaseous exchange in mud-dwelling shrubs, e.g. mangroves.

Pod A dry 1 to many-seeded dehiscent fruit, as applied to the fruit of Fabaceae, i.e. Caesalpiniaceae, Mimosaceae and Papilionaceae.

Podzol, Podsolic soil Any of a group of acidic, zonal soils having a leached, light-coloured, gray and ashy appearance. Also called spodosol.

Pollen cone Male cone or microstrobilus or pollen cone is structurally similar across all conifers, extending out from a central axis are microsporophylls (modified leaves). Under each microsporophyll is one or several microsporangia (pollen sacs).

Pollinia The paired, waxy pollen masses of flowers of orchids and milkweeds.

Polyandrous (Botany) having an indefinite number of stamens.

Polyembryonic seed Seeds contain many embryos, most of which are asexual (nucellar) in origin and genetically identical to the maternal parent.

Polygamous With unisexual and bisexual flowers on the same or on different individuals of the same species.

Polymorphic With different morphological variants.

Polypetalous (Botany) having a corolla composed of distinct, separable petals.

Pome A fleshy fruit where the succulent tissues are developed from the receptacle.

Pore A tiny opening.

Premorse Abruptly truncated, as though bitten or broken off as of a leaf.

Procumbent Trailing or spreading along the ground but not rooting at the nodes, referring to stems. *cf.* ascending, decumbent, erect.

Pro hyb. (Latin) as a hybrid.

Pro parte (Latin) in part.

Pro Parte majore (Latin) for the greater part.

Pro parte minore (Latin) for a small part.

Pro sp. (Latin) as a species.

Pro subsp. (Latin) as a subspecies.

Pro syn. (Latin) as a synoym.

Prophyll A plant structure that resembles a leaf.

Prostrate Lying flat on the ground.

Protandous Relating to a flower in which the anthers release their pollen before the stigma of the same flower becomes receptive.

Proximal End of any structure closest to the point of attachment. *cf.* distal.

Pruinose Having a thick, waxy, powdery coating or bloom.

Pseudocarp A false fruit, largely made up of tissue that is not derived from the ovary but from floral parts such as the receptacle and calyx.

Pseudostem The false, herbaceous stem of a banana plant composed of overlapping leaf bases.

Pteridophyte A vascular plant which reproduces by spores; the ferns and fern allies.

Puberulent Covered with minute hairs or very fine down; finely pubescent.

Puberulous Covered with a minute down.

Pubescent Covered with short, soft hairs.

Pulvinate Having a swelling, pulvinus at the base as a leaf stalk.

Pulvinus Swelling at the base of leaf stalk.

Pulviniform Swelling or bulging.

Punctate Marked with translucent dots or glands.

Punctiform Marked by or composed of points or dots.

Punctulate Marked with minute dots; a diminutive of punctate.
Purpurascent Purple or becoming purple.
Pusticulate Characterised by small pustules.
Pyrene The stone or pit of a drupe, consisting of the hardened endocarp and seed.
Pyriform Pear-shaped, a 3-dimensional shape; attached at the broader end. *cf.* obpyriform.
Pyxidium Seed capsule having a circular lid (operculum) which falls off to release the seed.
Raceme An indeterminate inflorescence with a simple, elongated axis and pedicellate flowers, youngest at the top. *adj.* racemose.
Rachilla The main axis of a grass spikelet.
Rachis The main axis of the spike or other inflorescence of grasses or a compound leaf.
Radiate Arranged around a common centre, as of an inflorescence of Asteraceae with marginal, female or neuter, ligulate ray-florets and central, perfect or functionally male, tubular, disc florets. *cf.* disciform, discoid.
Radical Arising from the root or its crown or the part of a plant embryo that develops into a root.
Ray The marginal portion of the inflorescence of Asteraceae and Apiaceae when distinct from the disc. Also, the spreading branches of a compound umbel.
Receptacle The region at the end of a pedicel or on an axis which bears one or more flowers. *adj.* receptacular.
Recurved Curved downwards or backwards.
Reflexed Bent or turned downward.
Regosol Soil that is young and undeveloped, characterised by medium to fine-textured unconsolidated parent material that maybe alluvial in origin and lacks a significant horizon layer formation.
Reniform Kidney shaped in outline.
Repand With slightly undulate margin.
Replicate Folded back, as in some corolla lobes.
Resinous Producing sticky resin.
Resupinate Twisted through 180°.
Reticulate Having the appearance of a network.
Retrorse Bent or directed downwards or backwards. *cf.* antrorse.
Retuse With a very blunt and slightly notched apex. *cf.* emarginated.
Revolute With the margins inrolled on the lower (abaxial) surface.
Rhizine A root-like filament or hair growing from the stems of mosses or on lichens.
Rhizoid Root-like filaments in a moss, fern, fungus, etc. that attach the plant to the substratum.
Rhizome A prostrate or underground stem consisting of a series of nodes and internodes with adventitious roots and which generally grows horizontally.
Rhizophore A stilt-like outgrowth of the stem which branches into roots on contact with the substrate.
Rhombic Shaped like a rhombus.
Rhomboid Shaped like a rhombus.
Rib A distinct vein or linear marking, often raised as a linear ridge.
Riparian Along the river margins, interface between land and a stream.
Rosette A tuft of leaves or other organs arranged spirally like petals in a rose, ranging in form from a hemispherical tuft to a flat whorl. *adj.* rosetted, rosulate.
Rostrate Beaked; the apex tapered into a slender, usually obtuse point.
Rostrum A beak-like extension.
Rosulate Having a rosette.
Rotate Wheel shaped; refers to a corolla with a very short tube and a broad upper part which is flared at right angles to the tube. *cf.* salverform.
Rotundate Rounded; especially at the end or ends.
Rugae Refers to a series of ridges produced by folding of the wall of an organ.
Rugose Deeply wrinkled.
Rugulose Finely wrinkled.
Ruminate (Animal) chew repeatedly over an extended period.
Ruminate endosperm Uneven endosperm surface that is often highly enlarged by ingrowths or infoldings of the surrounding tissue. *cf.* homogenous endosperm.
Rz value Is a numerical reference to the mesh/emulsion equalisation on the screen.
Saccate Pouched.
Sagittate Shaped like an arrow head.
Saline soils Soils that contain excessive levels of salts that reduce plant growth and vigour by altering water uptake and causing ion-specific toxicities or imbalances.

Salinity Is characterised by high electrical conductivities and low sodium ion concentrations compared to calcium and magnesium.

Salverform Applies to a gamopetalous corolla having a slender tube and an abruptly expanded limb.

Samara An indehiscent, winged, dry fruit.

Sand A naturally occurring granular material composed of finely divided rock and mineral particles range in diameter from 0.0625 μm to 2 mm. *adj.* sandy.

Saponins Are plant glycosides with a distinctive foaming characteristic. They are found in many plants, but get their name from the soapwort plant (*Saponaria*).

Saprophytic Living on and deriving nourishment from dead organic matter.

Sapwood Outer woody layer of the tree just adjacent to and below the bark.

Sarcotesta Outermost fleshy covering of Cycad seeds below which is the sclerotesta.

Scabrid Scurfy, covered with surface abrasions, irregular projections or delicate scales.

Scabrous Rough to the touch because of scattered rough hairs.

Scale Dry bract or leaf.

Scandent Refer to plants, climbing.

Scape Erect flowering stem, usually leafless, rising from the crown or roots of a plant. *adj.* scapose.

Scapigerous With a scape.

Scarious Dry, thin and membranous.

Schizocarp A dry fruit which splits into llongitudinally multiple parts called mericarps or cocci. *adj.* schizocarpous.

Sclerotesta The innermost fleshy coating of cycad seeds, usually located directly below the sarcotesta.

Scorpoid Refers to a cymose inflorescence in which the main axis appears to coil.

Scutellum (Botany) any of various parts shaped like a shield.

Secondary venation Arrangement of the lateral veins arising from the midrib in the leaf lamina.

Secund With the flowers all turned in the same direction.

Sedge A plant of the family Apiaceae, Cyperaceae.

Segmented Constricted into divisions.

Seminal root Or seed root originate from the scutellar node located within the seed embryo and are composed of the radicle and lateral seminal roots.

Senescence Refers to the biological changes which take place in plants as they age.

Sepal Free segment of the calyx. *adj.* sepaline.

Septum A partition or cross wall. *pl.* septa. *adj.* septate.

Seriate Arranged in rows.

Sericeous Silky; covered with close-pressed, fine, straight silky hairs.

Serrate Toothed like a saw; with regular, asymmetric teeth pointing forward.

Serrated Toothed margin.

Serratures Serrated margin.

Serrulate With minute teeth on the margin.

Sessile Without a stalk.

Seta A bristle or stiff hair. *pl.* setae. *adj.* setose, setaceous.

Setaceous Bristle-like.

Setate With bristles.

Setiform Bristle shaped.

Setulose With minute bristles.

Sheathing Clasping or enveloping the stem.

Shrub A woody plant usually less than 5 m high and many-branched without a distinct main stem except at ground level.

Silicula A broad, dry, usually dehiscent fruit derived from two or more carpels which usually dehisce along two sutures. *cf.* siliqua.

Siliqua A silicula which is at least twice as long as broad.

Silt Is soil or rock derived granular material of a grain size between sand and clay, grain particles ranging from 0.004 to 0.06 mm in diameter. *adj.* silty.

Simple Refer to a leaf or other structure that is not divided into parts. *cf.* compound.

Sinuate With deep wavy margin.

Sinuous Wavy.

Sinus An opening or groove, as occurs between the bases of two petals.

Sodicity Is characterised by low electrical conductivities and high sodium ion concentrations compared to calcium and magnesium.

Sodic soils Contains high levels of sodium salts that affects soil structure, inhibits water

movement and causes poor germination and crop establishment and plant toxicity.

Soil pH Is a measure of the acidity or basicity of the soil. See pH.

Solitary Usually refer to flowers which are borne singly and not grouped into an inflorescence or clustered.

Sorocarp Fruiting body formed by some cellular slime moulds, has both stalk and spore mass.

Sorophore Stalk bearing the sorocarp.

Sorosis Fleshy multiple fruit formed from flowers that are crowded together on a fleshy stem e.g. pineapple and mulberry.

Sorus A discrete aggregate of sporangia in ferns. *pl.* sori.

Spadix Fleshy spike-like inflorescence with an unbranched, usually thickened axis and small embedded flowers often surrounded by a spathe. *pl.* spadices.

Spathe A large bract ensheathing an inflorescence or its peduncle. *adj.* spathaceous.

Spatheate Like or with a spathe.

Spathulate Spatula or spoon shaped; broad at the tip and narrowed towards the base.

Spicate Borne in or forming a spike.

Spiculate Spikelet-bearing.

Spike An unbranched, indeterminate inflorescence with sessile flowers or spiklets. *adj.* spicate, spiciform.

Spikelet A small or secondary spike characteristics of the grasses and sedges and, generally composed of two glumes and one or more florets. Also applied to the small spike-like inflorescence or inflorescence units commonly found in Apiaceae.

Spine A stiff, sharp, pointed structure, formed by modification of a plant organ. *adj.* spinose.

Spinescent Ending in a spine; modified to form a spine.

Spinulate Covered with small spines.

Spinulose With small spines over the surface.

Spodosol See podsol.

Sporidia Asexual spores of smut fungi.

Sporangium A spore bearing structure found in ferns, fern allies and gymnosperms. *pl.* sporangia. *adj.* sporangial.

Sporocarp A stalked specialised fruiting structure formed from modified sporophylls, containing sporangia or spores as found in ferns and fern allies.

Sporophore A spore-bearing structure, especially in fungi.

Sporophyll A leaf or bract which bears or subtends sporangia in the fern allies, ferns and gymnosperms.

Sporophyte The spore-producing phase in the life cycle of a plant that exhibits alternation of generations.

Spreading Bending or spreading outwards and horizontally.

Spur A tubular or saclike extension of the corolla or calyx of a flower.

Squama Structure shaped like a fish scale. *pl.* squamae.

Squamous Covered in scales.

Squarrose Having rough or spreading scale-like processes.

Stamen The male part of a flower, consisting typically of a stalk (filament) and a pollen-bearing portion (anther). *adj.* staminal, staminate.

Staminate Unisexual flower bearing stamens but no functional pistils.

Staminode A sterile or abortive stamen, often reduced in size and lacking anther. *adj.* staminodial.

Standard Refers to the adaxial petal in the flower of Papilionaceae. *cf.* keel, wing.

Starch A polysaccharide carbohydrate consisting of a large number of glucose units joined together by glycosidic bonds α-1-4 linkages.

Stellate Star shaped, applies to hairs.

Stem The main axis of a plant, developed from the plumule of the embryo and typically bearing leaves.

Sterile Lacking any functional sexual parts which are capable of fertilisation and seed production.

Stigma The sticky receptive tip of an ovary with or without a style which is receptive to pollen.

Stilt root A supporting root arising from the stem some distance above the ground as in some mangroves, sometimes also known as a prop root.

Stipe A stalk that support some other structure like the frond, ovary or fruit.

Stipel Secondary stipule at the base of a leaflet. *pl.* stipellae. *adj.* stipellate.

Stipitate Having a stalk or stipe, usually of an ovary or fruit.

Stipulated Having stipules.

Stipule Small leaf-like, scale-like or bristle-like appendages at the base of the leaf or on the petiole. *adj.* stipulate.

Stolon A horizontal, creeping stem rooting at the nodes and giving rise to another plant at its tip.

Stoloniferous Bearing stolon or stolons.

Stoma A pore in the epidermis of the leaf or stem for gaseous exchange. *pl*. stomata.

Stone The hard endocarp of a drupe, containing the seed or seeds.

Stramineous Chaffy; straw-liked.

Striae Parallel longitudinal lines or ridges. *adj.* striate.

Striate Marked with fine longitudinal parallel lines or ridges.

Strigose Bearing stiff, straight, closely appressed hair; often the hairs have swollen bases.

Strobilus A cone-like structure formed from sporophylls or sporangiophores. *pl.* strobili.

Strophile An appendage at the hilum of certain plant seeds.

Strophiolate Furnished with a strophile or caruncle.

Style The part of the pistil between the stigma and ovary.

Sub- A prefix meaning nearly or almost, as in subglobose or subequal.

Subcarnose Nearly fleshy.

Sub-family Taxonomic rank between the family and tribe.

Subglobose Nearly spherical in shape.

Subretuse Faintly notched at the apex.

Subsessile Nearly stalkless or sessile.

Subshrub Intermediate between a herb and shrub.

Subspecies A taxonomic rank subordinate to species.

Substrate Surface on which a plant or organism grows or attached to.

Subtend Attached below something.

Subulate Narrow and tapering gradually to a fine point, awl-shaped.

Succulent Fleshy, juicy, soft in texture and usually thickened.

Suckers Young plants sprouting from the underground roots of a parent plant and appearing around the base of the parent plant.

Suffrutescent stem Stem woody at the base.

Sulcate Grooved longitudinally with deep furrows.

Sulcus A groove or depression running along the internodes of culms or branches.

Superior Refers to the ovary is free and mostly above the level of insertion of the sepals and petals. *cf.* inferior.

Suture Line of dehiscence.

Swidden Slash-and-burn or shifting cultivation.

Syconium A type of pseudocarp formed from a hollow receptacle with small flowers attached to the inner wall. After fertilisation the ovaries of the female flowers develop into one-seeded achenes, e.g. fig.

Symbiosis Describes close and often long-term mutualistic and beneficial interactions between different organisms.

Sympetalous Having petals united.

Sympodial Refers to a specialised lateral growth pattern in which the apical meristem. *cf* monopodial.

Synangium An organ composed of united sporangia, divided internally into cells, each containing spores. *pl.* synangia.

Syncarp An aggregate or multiple fruit formed from two or more united carpels with a single style. *adj.* syncarpous.

Syncarpous Carpels fused forming a compound pistil.

Synteny Presence of two or more genetic loci on the same chromosome.

Tannins Group of plant-derived phenolic compounds.

Taxon The taxonomic group of plants of any rank. e.g. a family, genus, species or any infraspecific category. *pl.* taxa.

Tendril A slender, threadlike organ formed from a modified stem, leaf or leaflet which, by coiling around objects, supports a climbing plant.

Tepal A segment of the perianth in a flower in which all the perianth segments are similar in appearance and are not differentiated into calyx and corolla; a sepal or petal.

Tetrasporangium A sporangium containing four haploid spores as found in some algae.
Terete Having a circular shape when cross-sectioned or a cylindrical shape that tapers at each end.
Terminal At the apex or distal end.
Ternate In threes as of leaf with three leaflets.
Testa A seed coat, outer integument of a seed.
Thallus Plant body of algae, fungi and other lower organisms.
Thyrse A dense, panicle-like inflorescence, as of the lilac, in which the lateral branches terminate in cymes.
Tomentose Refers to plant hairs that are bent and matted forming a wooly coating.
Tomentellose Mildly tomentose.
Torus Receptacle of a flower.
Transpiration Evaporation of water from the plant through leaf and stem pores.
Tree That has many secondary branches supported clear of the ground on a single main stem or trunk.
Triangular Shaped like a triangle, 3-angled and 3-sided.
Tribe A category intermediate in rank between subfamily and genus.
Trichome A hair-like outgrowth of the epidermis.
Trichotomous Divided almost equally into three parts or elements.
Tridentate Three toothed or three pronged.
Trifid Divided or cleft into three parts or lobes.
Trifoliate Having three leaves.
Trifoliolate A leaf having three leaflets.
Trifurcate Having three forks or branches.
Trigonous Obtusely three-angled; triangular in cross-section with plane faces.
Tripartite Consisting of three parts.
Tripinnate Relating to leaves, pinnately divided three times with pinnate pinnules.
Tripliveined Main laterals arising above base of lamina.
Triploid Describing a nucleus or cell that has three times ($3n$) the haploid number (n) of chromosomes.
Triveined Main laterals arising at the base of lamina.
Triquetrous Three-edged; acutely 3-angled.
Trullate With the widest axis below the middle and with straight margins; ovate but margins straight and angled below middle, trowel-shaped, angular ovate.
Truncate With an abruptly transverse end as if cut off.
Tuber A stem, usually underground, enlarged as a storage organ and with minute scale-like leaves and buds. *adj.* tuberous.
Tubercle A wart-like protuberance. *adj.* tuberculate.
Tuberculate Bearing tubercles; covered with warty lumps.
Tuberisation Formation of tubers in the soil.
Tuft A densely packed cluster arising from an axis. *adj.* tufted.
Turbinate Having the shape of a top; cone-shaped, with the apex downward, inversely conic.
Turgid Distended by water or other liquid.
Turion The tender young, scaly shoot such as asparagus, developed from an underground bud without branches or leaves.
Turnery Articles made by the process of turning.
Twining Winding spirally.
Ultisols Mineral soils with no calcareous material, have less than 10 % weatherable minerals in the extreme top layer of soil and with less than 35 % base saturation throughout the soil.
Umbel An inflorescence of pedicellate flowers of almost equal length arising from one point on top of the peduncle. *adj.* umbellate.
Umbellet A secondary umbel of a compound umbel. *cf.* umbellule.
Umbellule An, a secondary umbel of a compound umbel. *cf.* umbellet.
Uncinate Bent at the end like a hook; unciform.
Undershrub Subshrub; a small, usually sparsely branched woody shrub less than 1 m high. *cf.* shrub.
Undulate With an edge/margin or edges wavy in a vertical plane; may vary from weakly to strongly undulate or crisped. *cf.* crisped.
Unifoliolate A compound leaf which has been reduced to a single, usually terminal leaflet.
Uniform With one form, e.g. having stamens of a similar length or having one kind of leaf. *cf.* dimorphic.
Uniseriate Arranged in one row or at one level.

Unisexual With one sex only, either bearing the anthers with pollen or an ovary with ovules, referring to a flower, inflorescence or individual plant. *cf.* bisexual.

Urceolate Shaped like a jug, urn or pitcher.

Utricle A small bladdery pericarp.

Vaginate Forming or enclosed in a sheath.

Valvate Meeting without overlapping, as of sepals or petals in bud. *cf.* imbricate.

Valve One of the sections or portions into which a capsule separates when ripe.

Variant Any definable individual or group of individuals which may or may not be regarded as representing a formal taxon after examination.

Variegate, variegated Diverse in colour or marked with irregular patches of different colours, blotched.

Variety A taxonomic rank below that of sub-species.

Vein (Botany) a strand of vascular bundle tissue.

Veinlets Small veins.

Velum A flap of tissue covering the sporangium in the fern, Isoetes.

Velutinous Having the surface covered with a fine and dense silky pubescence of short fine hairs; velvety. *cf.* sericeous.

Venation Distribution or arrangement of veins in a leaf.

Veneer Thin sheet of wood.

Ventral (Botany) facing the central axis, opposed to dorsal.

Vernation The arrangement of young leaves or fronds in a bud or at a stem apex. *cf.* circinnate.

Verrucose Warty.

Verticil A circular arrangement, as of flowers, leaves or hairs, growing about a central point; a whorl.

Verticillaster False whorl composed of a pair of opposite cymes as in Lamiaceae.

Verticillate Whorled, arranged in one or more whorls.

Vertisol A soil with a high content of expansive montmorillonite clay that forms deep cracks in drier seasons or years.

Vertosols Soils that both contain more than 35 % clay and possess deep cracks wider than 5 mm during most years.

Vesicle A small bladdery sac or cavity filled with air or fluid. *adj.* vesicular.

Vestigial The remaining trace or remnant of an organ which seemingly lost all or most of its original function in a species through evolution.

Vestiture Covering; the type of hairiness, scaliness or other covering commonly found on the external parts of plants. *cf.* indumentums.

Vibratile Capable of to and fro motion.

Villose Covered with long, fine, soft hairs, finer than in pilose.

Villous Covered with soft, shaggy unmatted hairs.

Vine A climbing or trailing plant.

Violaxanthin Is a natural xanthophyll pigment with an orange color found in a variety of plants like pansies.

Viscid Sticky, being of a consistency that resists flow.

Viviparous Describes seeds or fruit which sprout before they fall from the parent plant.

Whorl A ringlike arrangement of leaves, sepals, stamens or other organs around an axis.

Winged Having a flat, often membranous expansion or flange, e.g. on a seed, stem or one of the two lateral petals of a Papilionaceous flower or one of the petal-like sepals of Polygalaceae. *cf.* keel, standard.

Xanthophylls Are yellow, carotenoid pigments found in plants. They are oxidised derivatives of carotenes.

Xeromorphic Plant with special modified structure to help the plant to adapt to dry conditions.

Xerophyte A plant which naturally grows in dry regions and is often structurally modified to withstand dry conditions.

Zygomorphic Having only one plane of symmetry, usually the vertical plane, referring to a flower, calyx or corolla. *cf.* actinomorphic.

Zygote The fist cell formed by the union of two gametes in sexual reproduction. *adj.* zygotic.

Common Name Index

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