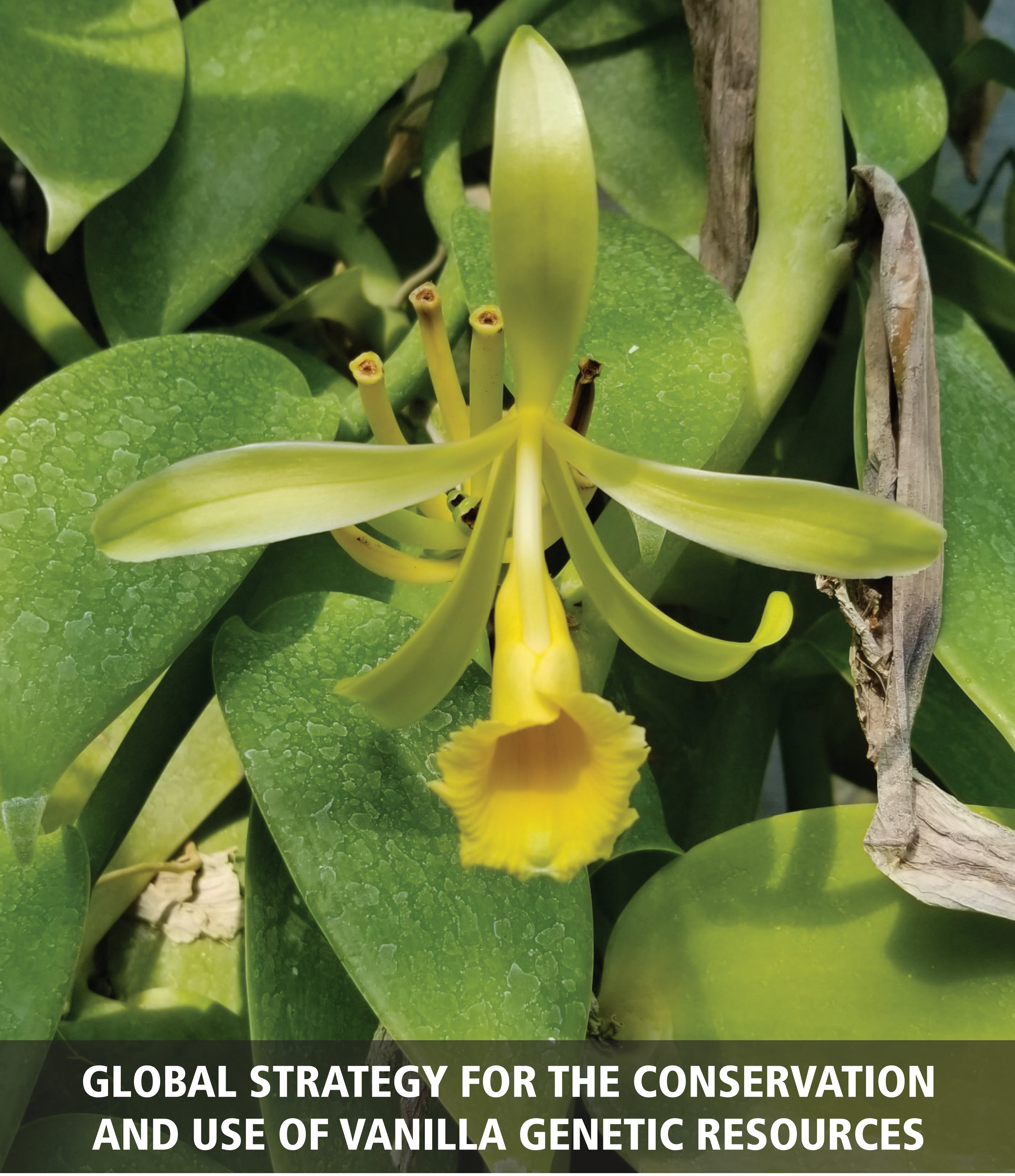

GLOBAL STRATEGY FOR THE CONSERVATION AND USE OF VANILLA GENETIC RESOURCES

With support from

CROP TRUST

The International Treaty
ON PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Federal Ministry of Food and Agriculture

COVER

Vanilla pompona flower. Photo: A. Chambers, University of Florida

DISCLAIMER

This report aims to provide a framework for the efficient and effective *ex situ* conservation and use of Vanilla genetic resources at global level. The Crop Trust considers this document to be an important framework for guiding the allocation of its resources. However, the Crop Trust does not take responsibility for the relevance, accuracy or completeness of the information in this document and does not commit to funding any of the priorities identified. This strategy document is expected to continue to evolve and be updated as and when circumstances change or new information becomes available.

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ACRONYMS

AFLP	amplified fragment length polymorphism
ABS	Access and benefit sharing
BUAP	Benemérita Universidad Autónoma de Puebla
BRC Vatel	Biological Research Center Vatel
BGCI	Botanical Gardens Conservation International
FOFIFA	Centre Nationale de la Recherche Appliquée au Développement Rural
CITES-2015	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CyMV	Cymbidium mosaic virus
Forv	*Fusarium oxysporum* forma *specialis radicis-vanillae*
GRIN	Germplasm Resource Information Network
GBIF	Global Biodiversity Information Facility
ISSR	inter simple sequence repeat
ITS	internal transcription spacers
IISR	Indian Institute of Spices Research
INBIOTECA	Institute of Biotechnology and Applied Ecology (Universidad Veracruzana, Mexico)
INISEFOR	Instituto de Investigación y Servicios Forestales
INIFAP	Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias
COGENT	International Coconut Genetic Resources Network
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
IUCN	International Union for Conservation of Nature
SPASHA	joint land sparing and land sharing approach
PNG	Papua New Guinea
QMS	quality management system
RAPD	random amplified polymorphic DNA
SAVA	Sambava, Antalaha, Vohemar, Andapa (region in Madagascar)
SNP	single nucleotide polymorphisms
SMTA	standard material transfer agreement
SOP	standard operating procedure
TCG	taxonomically complex group
CITRO	Tropical Research Center, (Universidad Veracruzana)

Vanilla planifolia. Photo: Maren Botanik/Wikimedia

EXECUTIVE SUMMARY

Vanilla is the only orchid genus known to produce a valuable crop commodity. The main species cultivated to produce vanilla are *Vanilla planifolia* Andrews, *V. x tahitensis* J.W. Moore and *V. pompona* Scheide. Botanically speaking, the fruit is a capsule, but it is commonly referred to as a “bean” or “pod.” The species commonly used to produce vanilla, *V. planifolia*, grows as a robust vine that can extend 20–50 meters.

Vanilla production and export are concentrated in 10 countries, with Madagascar well established as the world’s leader. Vanilla production is an important source of income for smallholder farmers and local economies in tropical areas of the world, where cultivation of *Vanilla* plants in traditional agroforestry systems or in eco-plantations is recognized to have a positive impact on biodiversity. However, global vanilla production and consumption are in a vulnerable situation, as inefficiencies in production and market systems have led to an unsustainable international market for the commodity. As there are viable sources of vanillin other than vanilla pods, the global vanilla industry is smaller than that of other spices such as black pepper or ginger.

The historical pattern of the plant’s distribution, propagation and cultivation has led to an extremely narrow genetic base for the cultivated species. This genetic uniformity poses a high risk to global vanilla production. Most cultivation of *V. planifolia* today can be traced back to one single origin of *V. planifolia* from Papantla, now in the state of Veracruz, Mexico. Therefore, it is essential to diversify the genetic base of the cultivars in farmers’ fields in order to improve tolerance or resistance to pests and diseases, increase tolerance to changing environments, and improve quality and yield. Several other *Vanilla* species have diversity that can be used for the improvement of

V. planifolia. In addition, several *Vanilla* species in section *Xanata* have unique fragrance and aroma profiles or medicinal uses with potential commercial value, and so could be cultivated in addition to *V. planifolia*, *V. x tahitensis* and *V. pompona*.

The genetic resources of vanilla are complex. Existing plant populations, including those with samples conserved in *ex situ* collections and those conserved *in situ* or *circa situm*, are highly vulnerable to genetic erosion and loss from deforestation, land-use change, pests and diseases, climate change and natural disasters. Safeguarding vanilla genetic diversity will require a concerted global effort, involving both *ex situ* conservation of accessions nationally or internationally and a combination of *in situ*, *ex situ* and *circa situm* approaches in an effective integrated strategy that considers market diversification, rural development and access and benefit-sharing agreements.

This strategy draws on a survey of 18 institutions that conserve accessions of *Vanilla* species. The survey results indicate that the current global system is not secure, efficient, or rational, with most collection holders identifying numerous gaps and vulnerabilities in key routine operations and facilities. Gaps were also identified in the use of procedures and protocols, such as standard operating procedures, quality management systems and conservation research. Finally, the lack of safety duplication and shortage of expert staff and annual funding for routine conservation for most accessions conserved globally are key vulnerabilities that need to be addressed.

The current global system for the conservation and use of vanilla genetic resources is not meeting international standards for conservation of vegetatively propagated crops for any collection holders. Generally, the system is insecure, with inefficient and poorly resourced operations, limited availability of plant material for users, limited sharing of accession-level information with users, and limited engagement of conservers and users globally, nationally and locally. These vulnerabilities have already resulted in the loss of valuable genetic resources from institutions in Mexico and Madagascar. This is not the sustainable, rational, secure and cost-effective system that is needed for the long-term conservation and use of one of the world's most widely used spices. Vanilla is a high-value commodity that is critically important to the income of hundreds of thousands of smallholder farmers and local communities in the tropics. However, vanilla conservation is of very low priority for international donors, national governments, public and private researchers, local authorities, local farmers, local and urban markets and consumers. This low priority poses a risk not only to *in situ* and *ex situ* conservation but also to the continued conservation of diversity in farmers' fields.

The survey respondents identified a number of advantages of improving the global system, and their responses point to the main priority actions for achieving improvements. Based on the survey results and a background review, this strategy identifies three objectives. To address these, three priority actions are required: (1) to hold a global workshop on vanilla genetic resources, (2) to establish a global fund for conservation and use and (3) to launch a global initiative designed to secure the long-term conservation of vanilla genetic resources *ex situ*, in farmers' fields and in protected areas.

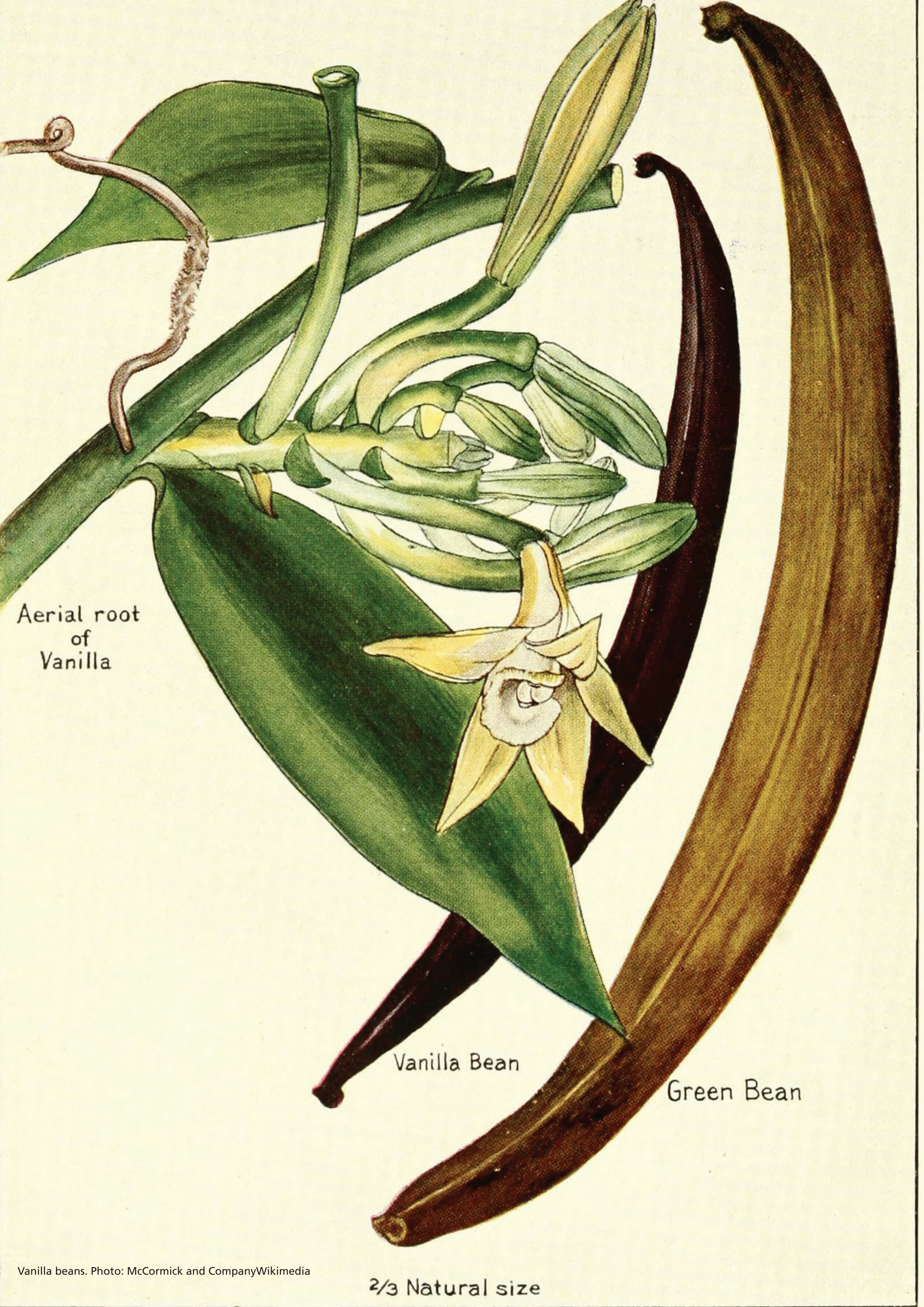
Curing vanilla beans. Photo: Sunil Elias/Wikimedia

1 INTRODUCTION

The Global Crop Diversity Trust (Crop Trust) is an international organization working to safeguard crop diversity through long-term *ex situ* conservation in genebanks. Since 2006, the Crop Trust has hired crop specialist to work with crop conservation communities to develop global *ex situ* conservation strategies for key global food crops and commodities, including internationally important commodities such as coffee and tea. Global conservation strategies facilitate a transition from a complex, fragmented and independent national or local crop conservation system to a more integrated, collaborative and cooperative global conservation system.

Although the genetic diversity of vanilla is recognized as an important resource both for securing future supply and for enhancing specific quality characteristics, there is no comprehensive global body of knowledge of the status of its *ex situ* and *in situ* conservation. There have been few publications on the history, current status and future needs of vanilla *ex situ* germplasm collections. Many of the accessions conserved in *ex situ* collections, as well as plants conserved *in situ* or on farm, could be vulnerable to loss due to pests and diseases, changes in temperature or rainfall distribution in natural areas, and natural disasters. They could also be lost due to changes in priorities, staffing or annual funding by the institutions, governments or individuals that manage the collections. The loss of an accession might mean the loss of a valuable source of improvement for vanilla production or quality. Furthermore, the ongoing genetic erosion in the wild due to inadequate protection or conservation means that any loss of diversity from *ex situ* collections could result in the loss of that diversity forever.

These threats can be mitigated by implementing a more coordinated, effective, cost-efficient and rational global system that secures the genetic resources of vanilla (including its wild relatives) for future generations and allows for greater exchange of material and better global information sharing. A strategy for the long-term conservation and use of vanilla genetic resources is an essential framework to guide the community of producers, industry and consumers in the development of such a global conservation system. Central to each global strategy is a set of priority actions, agreed to by the community, designed to address shortfalls in the current global conservation system. The Crop Trust and others will use these priority actions to identify the key investments needed to secure conservation and use over the long term. Further consultations with collection holders and various user groups will ensure a consensus on the priority needs and a commitment to an improved global system.



Vanilla beans. Photo: McCormick and CompanyWikimedia

Vanilla pompona beans. Photo: A. Chambers, University of Florida

2 BACKGROUND

Vanilla is the only orchid or terrestrial epiphyte currently used to produce an agriculturally important commodity. Botanically speaking, the vanilla fruit is a capsule, but it is commonly referred to as a "bean" or "pod." *Vanilla planifolia*, the main species cultivated to obtain vanilla, is a vine that can extend 20–50 m. It has round, dark-green, fleshy stems with very few branches. Adventitious roots form in the nodes to take up water and enable strong adhesion to a tree or other support. The vines can be propagated by stem cuttings. Inflorescences form in the axes of the leaves, with 10–12 flowers that open successively. The trumpet-shaped flowers are short lived, opening in the early morning and beginning to wilt by mid-morning. The fruit or pod grows in clusters of 8–10 pods, each with a fleshy, rounded shape of about 10 mm in diameter, with small black seeds. The fruits are harvested 8–9 months after hand pollination. After harvest, they are cured and dried using a 4–6-month curing process that develops the aroma and flavor for which vanilla is highly valued.

Vanilla has a long history as a valuable ingredient used to give flavor or fragrance to various food and non-food products, as set out in reviews of its history and use (Arditti et al. 2009; Rupp 2014; Sethi 2017; Ferrara 2019). The earliest reports of the use of vanilla come from the ancient Mayans, who used vanilla in a beverage made with cocoa and other spices. This culinary tradition was adopted by the Aztecs, who purchased processed vanilla from the Totonac of the east coast of Mexico. The Spanish conquest of the Aztecs led to the introduction of vanilla into western Europe. The vine was grown in French and English botanical gardens, but no seeds were produced until 1836, when a Belgian botanist noted that the native pollinator had not been brought to Europe with the vine and successfully pollinated flowers manually. In 1841, in Réunion, Edmond Albius implemented an effective hand pollination method that spread to other production areas such as Madagascar and finally back to Mexico, where it is now used in addition to natural insect pollination.

Economic importance of vanilla

Vanilla is a very important source of income for smallholder farmers and local economies in some tropical areas of the world. According to FAO data (FAOSTAT), world production of vanilla between 2010 and 2019 was about 8,000 tonnes per year (Figure 2.1), concentrated in a small number of countries. Figure 2.2 shows the top 10 producing countries between 2010 and 2019, according to FAOSTAT data. According to export estimates (Chakib 2019), in the period 2012–2017, Madagascar was the world's largest vanilla exporter (65% of world production), followed by Indonesia, Papua New Guinea (PNG), India and Uganda.

Madagascar has long been the world's leading producer and exporter of vanilla (Chakib 2019). Despite some competition from other countries, especially when prices are high, its leadership position is not facing any threats in the short or medium term. The vanilla sector in Madagascar is estimated to involve more than 100,000 households producing vanilla, thousands of intermediaries in trading and transportation, and more than 200,000 mainly local jobs in production and processing (Chakib 2019). Vanilla accounted for about 7% of Madagascar's gross domestic product (GDP) in 2017. Although the industry offers increasing economic benefits to Madagascar, production and processing are reported to be underdeveloped with poor infrastructure, health and education.

According to Aust and Hachmann (2020), the price of vanilla has been falling rapidly in the 2019 season

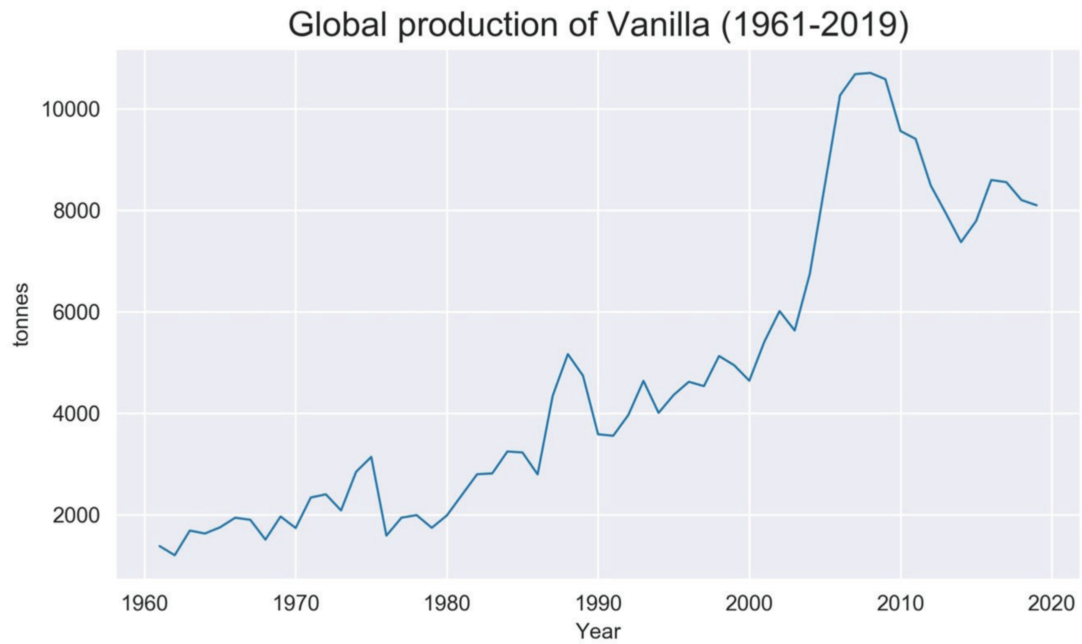


Figure 2.1 World production of vanilla obtained by aggregating production by country. (Data source: FAOSTAT)

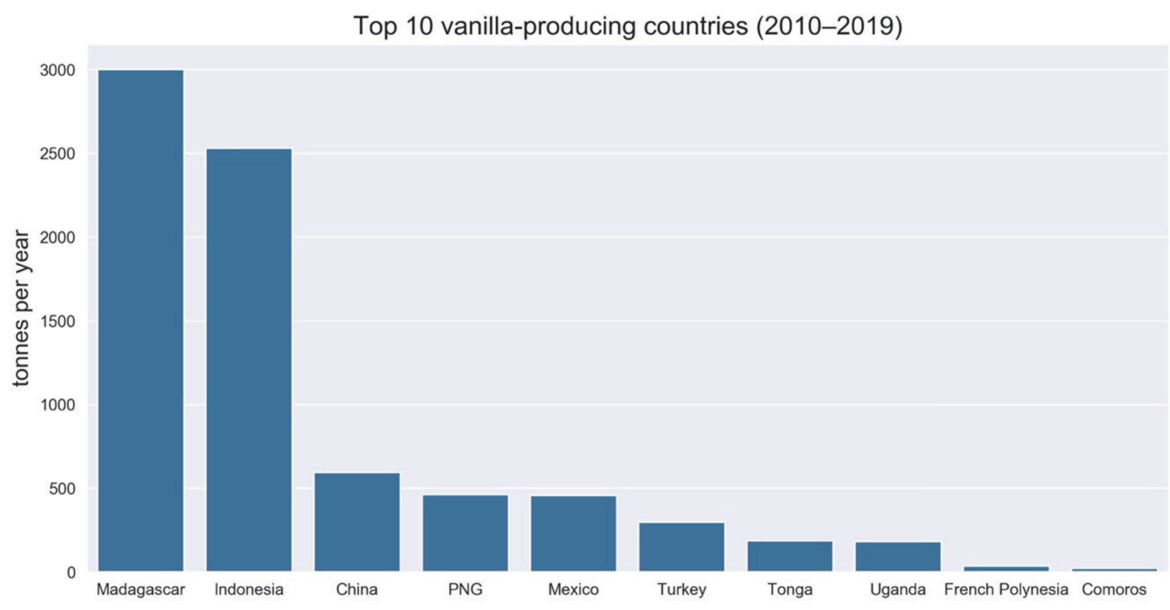


Figure 2.2. Top 10 vanilla-producing countries (2010–2019). (Data source: FAOSTAT)

due to larger crops in Madagascar, Indonesia, Uganda and the Comoros; furthermore, they predicted that Uganda, Indonesia and PNG would supply more of the international demand. The 2020 price for vanilla was 60–75% less than the price at its peak in 2017–2018, which appeared to be more sustainable; it was predicted to fall further, with volatility over the short term, before stabilizing in the long term. This price fall could have a significant negative impact on some producer countries, such as the Comoros.

During the period 2008–2017, the main importers of vanilla by volume were the United States (24%), France (15%), the United Kingdom (9%), Germany (8%) and Canada (5%) (Chakib 2019). Many of these countries import vanilla pods for processing or direct sale, and then export vanilla extract. About 90% of vanilla is used in products intended for the food and perfume industries in North America and Europe (Bomgardner, 2016). In terms of import/export balance, the United States is, by far, the main consumer of vanilla, representing on average 61% of the consumption of the top eight importing countries. Additional information on the economic importance of vanilla is provided in Annex I, which summarizes relevant results from a study by Khoury et al. (2019).

Natural vanilla markets

Naturally cultivated vanilla is the second most expensive spice after saffron. Production and processing of high-quality vanilla pods requires specialized knowledge and skills developed over years of experience. There are several aromatic types within *Vanilla planifolia*. The most popular is bourbon vanilla, with its clear and creamy flavors; bourbon vanilla is produced mainly on islands in the Indian Ocean, including Réunion, Madagascar, the Comoros and the Seychelles, as well as some in India. The main producing region in Mexico is the Totonicapán region, which has a reputation for producing the best vanilla pods, with a profile that is similar to bourbon and a spicy fragrance that is preferred for baked goods. Java vanilla, produced in Indonesia, is judged as being of lower quality than bourbon vanilla. It has smoky characteristics that are the result of the curing process used. The supply from Uganda is limited but it has a bold flavor profile with high levels of vanillin and its fragrance includes a hint of chocolate. There is little genetic difference in the *V. planifolia* germplasm grown in these various regions, so these differences in the product are likely the result of the production environment and the methods used for pod curing (Bory et al. 2008; Lubinsky et al. 2008c), as well as the pod microbiome (Khoyratty et al. 2015).

Sinha et al. (2008) reported that there are around 250 volatile compounds in *V. planifolia*, of which four are phenols that are recognized as indicators of commercial quality: vanillin, p-hydroxybenzaldehyde, vanillic acid and p-hydroxybenzoic acid. Ferrara (2019) described the basic products (vanilla extract, oleoresin, absolute vanilla and powdered vanilla) that are made from cured vanilla for flavoring or fragrance. Each product has its own organoleptic, physical and functional characteristics that are determined by the choice of pods used (such as the particular species, variety or geographic location) and the method used to treat them.

Alternative sources of vanillin have been widely used since the late 19th century, when chemists succeeded in deriving vanillin from less expensive sources such as petrochemicals, lignin from wood, clove oil and other minor sources. Currently, about 85% of vanillin comes from guaiacol that is synthesized from petrochemicals (Sethi 2017). Synthesis of vanillin is not only easier but also at least 25 times cheaper than extraction from vanilla pods. There are also alternatives for the synthesis of vanillin from more natural sources, such as spruce tree lignin, eugenol derived from clove oil or fermentation from ferulic acid derived from rice bran and glucose by yeast (Rupp 2014; Bomgardner 2016; Rains 2019). Gallage and Moller (2015) reviewed the current state of biotechnology-based vanillin synthesis using ferulic acid, eugenol and glucose as substrates and bacteria, fungi or yeast as the microbial production host. They also highlighted the future potential use of knowledge of the *de novo* biosynthetic pathway of vanillin in *V. planifolia* by vanillin synthase.

In 2015, the food industry pledged to eliminate artificial flavors from their products; as a result, the industry began seeking alternative "natural" sources of vanilla flavoring that were cheaper and more easily available than real vanilla. This shift happened at a time when the price of real vanilla was very high (Bomgardner 2016). The high prices led food manufacturers to introduce new sources of biologically derived vanilla or substitute new flavors as an alternative to real vanilla in their product recipes, with little likelihood that they would shift to real vanilla when the price fell again. The result was a contraction in the market for real natural vanilla, a sector with many smallholder farmers. Therefore, while there is demand for real natural vanilla, its use is increasingly restricted to high-value specialty products given the unpredictability of the price of the raw ingredient.

Bythrow (2005) reviewed the traditional medicinal uses of vanilla and the medical benefits of vanillin. In a review of the various pharmacological properties and therapeutic uses of vanilla, Ferrara (2019) reported that the plant has antibacterial and anti-mutagenic activity in bacteria. Furthermore, there is preliminary support in the scientific literature that vanilla has health benefits for several chronic conditions, such as the use of olfactory exposure to soothe infants and diminish sleep apnea, but additional research is required (Singletary 2020 and Arya et al 2021). Therefore, in the future there could be new high-value market opportunities for *Vanilla* species.

Natural vanilla extract from vanilla pods accounts for only about 1% of the market for vanilla extract, as vanillin can also be produced through chemical synthesis, bioconversion of other organic compounds and biosynthesis (Priefert et al. 2001). For this reason, the natural vanilla industry is smaller than other spices, such as pepper or ginger, and much smaller than other internationally traded commodities, such as coffee or cocoa. The world market for natural vanilla has been projected to increase by about 1.3% on average per year to 2025 based on growing demand for real vanilla in the food and medical sectors (Bomgardner 2016). Due to inefficiencies in both production and market systems, the international market for vanilla has become unsustainable, which needs to be addressed (Cadot et al. 2006; Bomgardner 2016; Chakib 2019; Rains 2019; Reel 2019; Aust & Hachmann 2020).

Vanilla production systems

Vanilla vines produce best at temperatures of 21–32 °C (but can sustain growth at cooler temperatures), 80% relative humidity and annual rainfall of at least 1500 mm, distributed fairly evenly throughout the year. Production is optimal when grown at 0–600 m above sea level. Vanilla is vulnerable to dry spells, heat waves and extreme winds such as cyclones, hurricanes and tropical storms. Vanilla is thus highly sensitive to the impacts of climate change in most current areas of production.

Vanilla vines require strong support in the form of trees or frames, as well as companion trees or screening to ensure they receive shade. Vanilla has traditionally been produced in forestry and agroforestry systems that range from semi-forest to intercropping with fruit trees or other tree crops. De La Cruz Medina et al. (2009) described the crop management activities required for a range of production systems, with activities becoming more labor and input intensive for shade-house systems compared to forestry-based systems. Several studies (Espinoza-Perez et al. 2019; Hanke et al. 2019; Hending et al. 2020) compared the biodiversity in natural and secondary forest with a range of vanilla production systems. All these studies concluded that intensifying the production system through increased plant density, reduction of the forest cover and the use of introduced plant species to support the vines led to a significant reduction in biodiversity. Espinoza-Perez et al. (2019) found that the plant species used to support the vanilla vine have other important traditional uses. Therefore, strategies to increase the yield and productivity of vanilla must ensure the ongoing conservation of the biodiversity and ecosystem services that sustain these systems. This is an important consideration when designing intensified production systems and when breeding new cultivars for traditional agroforestry systems.

Hanke et al. (2019) assessed the social, economic and ecological benefits of vanilla production for smallholder farmers in the region where about 80% of Malagasy vanilla is harvested. Vanilla is a labor-intensive crop produced in traditional cropping systems, with no mechanization or agricultural inputs used. All work is done manually: clearing the plots, planting the tutor trees, training the vanilla vines, weeding, hand pollinating each vanilla flower, and harvesting the maturing pod. Theft of the vanilla from the field or during the curing process has become a widespread problem that requires either substantial resources to protect the crop or harvesting the pod when immature, which reduces the quality and quantity of the vanillin.

Key vulnerabilities have been identified in the vanilla production system in the Totonacapan region of Mexico, the center of origin for *V. planifolia* (Herrera-Cabrera et al. 2012). Smallholder farmers who produce vanilla in Mexico were found to experience a high incidence of pests and diseases in their plantings, but lacked the necessary knowledge on genetic improvements, biocontrol measures and pest/disease diagnosis to manage them (Borbolla-Perez et al. 2017). Consequently, establishing or restoring plantations depended upon having a source of trustworthy, quality cuttings. Market constraints limited the profitability and consistent supply of quality vanilla pods from smallholder farmers in Mexico.

Vanilla production and processing are highly specialized skills that require considerable experience. Shriver (2013) compared production and value chain constraints for vanilla in two zones of Madagascar. In one of the zones, workers on plantations had knowledge and experience in vanilla production; in the other zone, many farmers had abandoned vanilla production, resulting in challenges in re-establishing plantations and intensifying production. Neither zone had a supplier of quality planting material, leading to a slow process of improved productivity.

Several studies have identified risks to vanilla production and quality, such as damage from cyclones and hurricanes or any political or economic situation that results in early harvest of pods or delay in pod marketing (Herrera-Cabrera et al. 2012; Shriver 2013; Borbolla-Perez et al. 2017; Sethi 2017; Chakib

2019; Hanke et al. 2019; Rains 2019; Veldhuyzen van Zanten 2019; Oon 2020). Fluctuations in supply, quality and price have had a long-term impact on farmers' willingness to invest in vanilla production. For example, the average production in Madagascar and Uganda was found to be only about 10% of the productivity benchmark of 500 kg per hectare (Veldhuyzen van Zanten 2019). Smallholder farmers have limited ability to shift crops when prices are low or to respond to higher prices with replanting or increased planting given the period of 3–4 years from planting to harvesting. This timeframe also restricts farmers' ability to shift vanilla cropping from one location to another. Actions suggested to help slow or reverse the decline in production and reduce the risk of biodiversity loss include: better prices for growers; improved, consistent quality of processed pods; restoration of the traditional production system; and active research and breeding programs that promote new technological packages to increase productivity, which should include new, improved varieties (Herrera-Cabrera et al. 2012).

Many buyers are making ongoing efforts to reduce risks, increase quality and encourage sustainable production through grower programs designed to improve the lives of producers while sustaining the supply of real vanilla. One approach implemented by exporters and importers is the creation of contract farming arrangements with local sourcing centers for buyers; these arrangements have been found to lead to improved socioeconomic status for farmers as well as higher production and market quality of the vanilla pods (Hanke et al. 2019). Furthermore, a shift has been seen in the vanilla markets in Madagascar and Uganda, with more multinational companies investing in supply chain relationships and projects that work directly with farmers and farmer organizations (Veldhuyzen van Zanten 2019). These projects create opportunities for more technical assistance and adequate trade structure to close the income gap for sustainable production. It was estimated that about 20% of farmers in Madagascar are already integrated with the supply chain with contracts or certification.

Another option that is being explored is to establish a living income reference price for vanilla (Veldhuyzen van Zanten 2019), which is set to meet the minimum production and market conditions for farmers to earn enough for a decent standard of living. In 2015, the Sustainable Vanilla Initiative was established as a voluntary industry initiative that "aims to promote long-term stable supply of high-quality, natural vanilla that is produced in a socially, environmentally and economically sustainable manner" (Sustainable Vanilla Initiative 2021). It currently has 28 members that collectively represent over 70% of global vanilla pod purchases (see Sustainable Vanilla Initiative (2021) for its focus and programs).

Efforts to increase supply to meet increased demand have proven to be a slow process for producers and are being further hampered by the impacts of climate change. Suppliers and consumers of real natural vanilla are also facing increased costs for the raw ingredient, fluctuations in availability and quality, and greater availability of natural alternatives. As a result, global vanilla production and consumption have many vulnerabilities and constraints, as well as new market opportunities. Several studies have concluded that focusing on ensuring a more sustainable income from vanilla would facilitate a stable market, with increased quality and production in more diverse agroforestry systems in the main production areas, such as Madagascar (Herrera-Cabrera et al. 2012; Flanagan and Mosquera-Espinosa 2016; Veldhuyzen van Zanten 2019; Hending et al. 2020). In Colombia (Flanagan and Mosquera-Espinosa 2016), Costa Rica (Watteyn et al. 2020) and the Totonacapan region of Mexico (Herrera-Cabrera et al. 2012), where there are species of vanilla with unique fragrances and aroma profiles that have commercial potential and could be cultivated along with *V. planifolia*, a market product diversification strategy has been proposed to sustain income and expand production of vanilla outside traditional cultivated areas.

VANILLA (Orchid and Bean)

⅝ Linear Measure

Vanilla pompona beans. Photo: A. Chambers, University of Florida

Vanilla planifolia being hand polinated. Photo: Forest and Kim Starr/Wikimedia

3 VANILLA GENETIC RESOURCES

The main cultivated species of vanilla, *Vanilla planifolia* Jacks., *V. x tahitensis* J.W. Moore and *V. pompona* Scheide, are all members of the genus *Vanilla*, which belongs to the taxonomic subtribe Vanillinae, in the tribe Vanilleae, within the subfamily Vanilloideae in the orchid family, Orchidaceae, (Cameron 2009). *Vanilla* is a tropical genus with native species distributed between the 27th North and South parallels in all continents (except Australia) and on remote islands in the Indian Ocean (including Madagascar) (Bouetard et al. 2010; Rodolphe et al. 2011).

The center of origin of the genus *Vanilla* is South America, but its evolutionary history is based upon transoceanic migration events that account for the biogeographic pattern of distribution of the genus. The first transoceanic event was the dispersal from America to Africa, where it separated into two subgenera, *Vanilla* and *Xanata*, about 152 million years ago (Bouetard et al. 2010; Gigant et al. 2011). Thereafter, the *Xanata* subgenus divided into two sections. Section *Xanata* developed in Central and South America and includes all the aromatic *Vanilla* species. The second section, *Tethya*, named after the ancient Tethys Sea (Soto-Arenas and Cribb 2010), developed putatively about 24 million years ago through transoceanic dispersion to the paleotropics of Africa. The third transoceanic dispersal was from Africa to Asia, then from Africa to the southwest Indian Ocean islands, and finally from Africa to the Caribbean and West Indian Islands (Bouetard et al. 2010; Gigant et al. 2011).

Taxonomic classification in the *Vanilla* genus has been based upon vegetative and floral characteristics and is challenging because most herbarium accessions lack the floral parts or present a poor state of flowering material (Soto-Arenas and Cribb 2010; Gigant et al. 2011; Andriamihaja et al. 2020; Karremans et al. 2020). The small populations of *Vanilla* species and their irregular flowering are among the factors that hamper the collection of fertile herbarium specimens (Soto-Arenas and Cribb 2010).

Andriamihaja et al. 2020 (page 10) concluded that the *Vanilla* genus fits the criteria defined by Ennos et al. (2005) for "Taxonomically Complex Groups" (TCGs) due to its "clonal reproduction or self-fertilization, interspecific hybridization between sympatric species, and polyploidization capacity". Karremans et al. (2020) reported that, in the first 250 years of exploration and naming of *Vanilla* species, about 100 species were recognized in the tropics globally; another 32 *Vanilla* species have been proposed as new in the past 32 years, principally within previously underexplored regions of South America (e.g. De Fraga et al. 2017; Barona-Colmenares 2018; Damian and Mitidieri 2020).

Karremans et al. (2020) revisited recently proposed taxonomic classification from the neotropics and extended the distribution of 10 previously described species. They concluded there was a need to fully consider historical records from the floras of other regions before proposing new species. Bory et al. (2010) found that a combination of taxonomy, morphological traits, ecological characteristics, reproductive biology, cytogenetics and genotypic assessment with molecular markers is needed in the full taxonomic revision of the genus. Karremans et al. (2020) suggested there was a need to revise the classification of neotropical species further by using molecular approaches as tools and continued input from herbarium specimens and classical descriptive taxonomy identified by experts.

The *Vanilla* genus has two subgenera (Soto-Arena and Cribb 2010): *Vanilla* and *Xanata*. The subgenus *Vanilla* contains species that were previously classified as subsection *Membranaceae*. All other species are classified into subgenus *Xanata*, which has two sections: *Xanata*, which corresponds to American species, and *Tethya*, which corresponds to African, Asian, and Caribbean species. The total number of species in the *Vanilla* genus remains unclear (Menchaca and Lozano 2018). In 2020, we initially compiled a list of 129 *Vanilla* species, considering synonyms, from several plant taxonomy databases: World Checklist of Selected Plant Families (2020); Tropicos.org (2020) and GBIF (2020). We finalized this list of 118 species (Annex IV) based on the revision of neotropical species in Karremans et al. (2020). The distribution of species by section and region is given in Figure 3.1. Most species are classified in section *Tethya* and are the only species to originate from Africa, Asia, and the Caribbean. All the species in sections *Xanata* and *Membranacea* originate from Central or South America.

The so-called aromatic group of species from the genus *Vanilla* (Flanagan et al. 2019) includes 38 species from subgenus *Xanata* section *Xanata*. These species originate from the neotropics, ranging from Florida to Mexico to the south of Brazil, excluding the Caribbean islands (Soto-Arenas and Cribb 2010; Karremans et al. 2020). Three of the species in section *Xanata* are of global agricultural importance: *V. planifolia* is the source of most of the cultivated vanilla, and *V. x tahitensis* and *V. pompona* are grown on a local scale (French Polynesia and Caribbean, respectively). In Central America, some other species are used locally. The center of origin of cultivated species ranges from southwestern Mexico, through Central America and into northwest South America (Flanagan and Mosquera-Espinosa 2016; Karremans et al. 2020). However, due to dispersal of cultivated *V. planifolia* and *V. x tahitensis* throughout the world, there are secondary centers of cultivation, especially in the Indian Ocean region (Madagascar and Réunion) and in French Polynesia.

Interspecific recombining ability within section *Xanata* is known. For example, *V. planifolia* can be crossed with *V. odorata* (which resulted in the economically important hybrid *V. x tahitensis*). *Vanilla planifolia* × *V. pompona* hybrids are used in commercial production in Costa Rica and Haiti (Belanger and Havkin-Frankel 2011). Successful interspecific crosses of *V. planifolia* with other members of the aromatic group of *Vanilla* species have been also made, including with *V. palmarum*, *V. insignis*, *V. bahiana* and *V. phaeantha* (Bory et al. 2008a; Bory et al. 2010; Li et al. 2020). American *Vanilla* species from section *Xanata* are generally perceived to be valuable genetic sources for improving commercial vanilla cultivars, especially given their aromatic nature and similarity to *V. planifolia*.

There are 62 species from section *Tethya* in subgenus *Vanilla* distributed throughout Africa, Asia and the Caribbean region (Figure 3.1). Intercrossing between *V. planifolia* and *V. aphylla*, a member of the *Tethya*

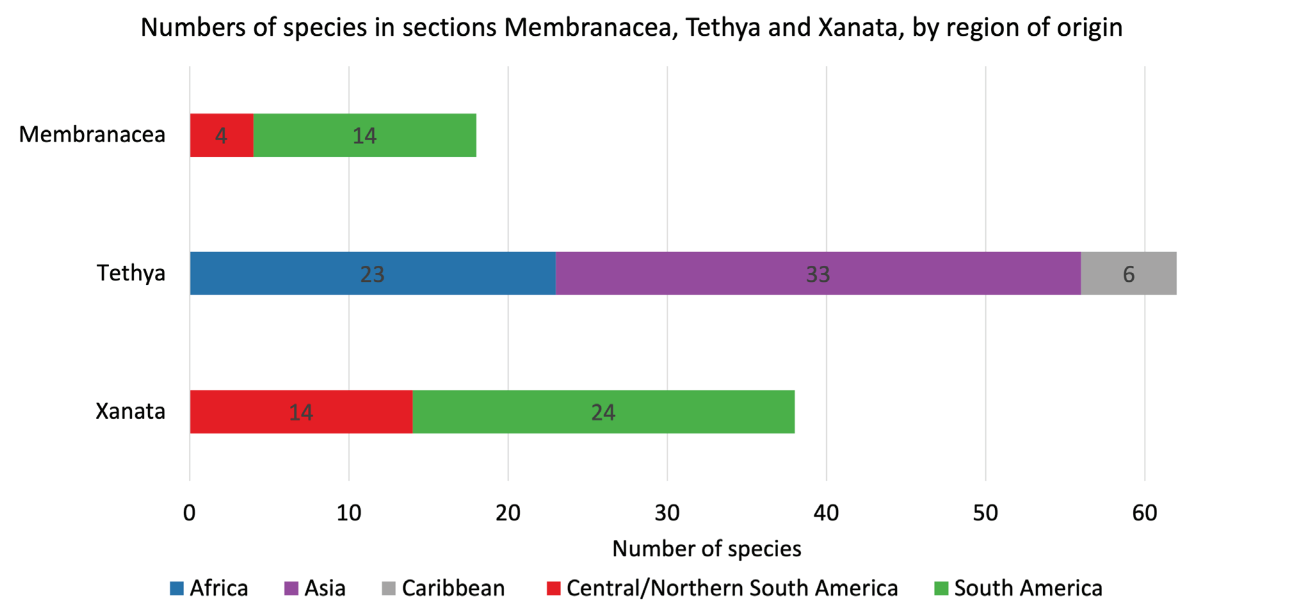


Figure 3.1 Number of species in sections *Xanata* and *Tethya* (subgenus *Xanata*) and in section *Membranacea* (subgenus *Vanilla*), by origin in Africa, Asia, Caribbean, Central and South America.

section, has been successful (Divakaran et al. 2006). These species could be used as a source of adaptation to biotic stresses or disease-resistance traits but, as they are non-aromatic, they are of less interest for improving cultivated vanilla.

Membranacea is the only section in subgenus *Vanilla* of genus *Vanilla*. These 18 species (Figure 3.1) are distantly related to section *Xanata* (Duvignau 2012). Their origin is restricted to South America (14 species) and Central America (4 species). There are no reported interspecific hybrids of *Membranacea* species with the aromatic vanilla species in subgenus *Xanata*. Thus, *Membranacea* species are not valued for genetic improvement of cultivated vanilla.

History of cultivation

In Mesoamerica, several *Vanilla* species were used and cultivated by the ancient Maya, Aztecs and Totonacs (Menchaca and Lozano 2018) and today they are still propagated for local uses. These species include *V. planifolia*, *V. pompona*, *V. odorata* and *V. insignis*.

Vanilla planifolia now accounts for about 95% of vanilla production (Lubinsky et al. 2008a). Throughout its cultivation history, there has not been any human-driven phenotypic change associated with increased suitability for cultivation (domestication complex) and there are no consistent morphological differences between wild and cultivated *V. planifolia* (Schlüter et al. 2007; Lubinsky et al. 2008a). This has been attributed to several factors: that vanilla is a relatively young crop species with a long sexual generation time, vanilla's slow evolution due to clonal propagation, and its cultivation history (Lubinsky 2007; Lubinsky et al. 2008a). However, Chambers et al. (2021) in the analysis of the results of a genotyping-by-sequencing study including 169 accessions of *V. planifolia* from different countries, found three types of *V. planifolia.*

The plant material in most of the global area cultivated with *V. planifolia* today likely traces back to a single origin in Papantla, in the state of Veracruz, Mexico. The Totonac people used vanilla as a cash crop for more than 250 years, but there is no evidence of any significant cultivation, as it was gathered from the forest rather than farmed (Lubinsky et al. 2008a). The only early evidence of cultivation was from the Mayan lowlands, where it was associated with cocoa production (Kourí 2004). Lubinsky et al. (2008a) described the historical evidence for vanilla production as part of the cultivation system of economic plants in the Maya region on the Pacific coast of Guatemala and Belize. The vanilla commodity then became associated with Veracruz as its last port of call before crossing the transatlantic during colonial times. Papantla was the first region to export vanilla to Europe in the 18th century, due to its proximity to important shipping ports (Kourí 2004). In the mid-19th century, production took off in the Indian Ocean islands, dislodging Papantla as the only place of cultivation. *Vanilla planifolia* from the Oaxaca and Maya regions is genetically differentiated from that in the Papantla region (Lubinsky et al. 2008a).

In the early 19th century, vanilla was clonally propagated and established in European botanical gardens. From there, it was transferred as clonal planting material to European colonies in Africa, Asia and the Indian Ocean (Fouche and Jouve 1999; Bory et al. 2008a; Gigant et al 2011). Single locus genetic data have shown that one genotype (clone) of *V. planifolia* was distributed from Papantla throughout the whole world (Lubinsky et al. 2008a; Lubinsky et al. 2008b), resulting in the genetic uniformity of the crop, in contrast to wild vanilla populations from other regions in Mexico and Central America, where sexual reproduction has led to higher diversity (Lubinsky et al. 2008a). However, some genetic diversity is also found within accessions of *V. planifolia* (Chambers et al. 2021).

The second most cultivated vanilla species (<5% of world production), *V. x tahitensis*, has not been found in the wild. It is a putatively human-mediated hybrid between *V. planifolia* and *V. odorata* made between 1350 and 1500. *Vanilla x tahitensis* was perhaps brought from the Maya region along the Pacific coast of Guatemala or Belize to the Philippines (where it is absent today), and from there, in the mid-19th century, to French Polynesia (Lubinsky et al. 2008b; Chambers et al. 2021). This species is now cultivated mainly in French Polynesia and Papua New Guinea (Lubinsky et al. 2008b). It is also grown commercially in Ecuador and occasionally found in Central America and Florida.

Several cultivars of *Vanilla planifolia* have been phenotypically differentiated in local production areas (Soto-Arenas and Dressler 2010). In Central America, the cv. Mansa, cv. Variegata and cv. Oreja de Burro have been described. After the arrival of *V. planifolia* in the Indian Ocean region, further vanilla cultivars were developed from introduced material, probably from the Mexican cv. Mansa (Soto-Arenas and Dressler 2010), through somatic mutations, auto-polyploidization (triploid "stérile" and tetraploid "grosse vanille") and even through sexual reproduction (cultivar 'Aiguille') (Bory et al. 2010; Gigant et al. 2011). In French Polynesia, several cultivars of *V. x tahitensis* were developed from the originally introduced material (Bory et al. 2008a). The Tahitian vanilla Biological Resource Center in French Polynesia conserves 321 Vanilla accessions, many of these are hybrids developed by the Etablissement Vanille de Tahiti (Roux-Cuvelier et al. 2021).

Bory et al. (2008c) and Lubinsky et al. (2008a) concluded that the morphological diversity described for production areas in Mexico, Réunion and Madagascar did not reflect great genetic diversity and all material had originated from a single introduced genotype from Papantla in Mexico. This morphological diversity has derived mostly from point mutations with large phenotypic effects accumulated during vegetative reproduction. However, there was one rare phenotype that was derived from a selfed seed and another that was a result of polyploidization. Dequaire (1976) and Lepers-Andrzejewski et al. (2011) found higher diversity within the various morphotypes in *V. x tahitensis* in French Polynesia than in *V. planifolia* from Réunion. This is due to the hybrid nature of the original planting material introduced and the subsequent selection of new variants from the selfed progeny from this interspecific hybrid.

Utilization of genetic resources

According to Gigant et al. (2011), the genetic diversity in cultivated *V. planifolia* and *V. x tahitensis* is a result of the initial level of diversity during the introductions and subsequent production practices. The initial introduction and all subsequent cultivation were based upon clonal propagation. The whole history of *V. planifolia* dissemination is linked to Réunion and Veracruz in Mexico. The crop is propagated vegetatively through cuttings and there are no natural pollinators outside the center of origin, so all cultivation depends upon hand selfing. Thus, the level of diversity in production areas outside the center of diversity is expected to be low, even though farmers do recognize cultivars with distinct morphological characteristics. This history of dissemination and cultivation has led to an extremely narrow genetic base of the crop in commercial production (Besse et al. 2004; Schlüter et al. 2007; Bory et al. 2008a; Flanagan et al. 2019). This genetic uniformity has made global vanilla production extremely susceptible to diseases, such as fusarium root rot, and pests (Hernández-Hernández 2011). Increased stress is associated with climate change; for example, smallholder farmers are suffering losses due to a high rate of premature flower abortion associated with high temperature (Borbolla-Perez et al. 2016).

Characterization and evaluation of vanilla genetic resources

There has been relatively little research on the evaluation and improvement of vanilla genetic resources, despite the crop's importance in low-altitude humid tropical regions (Flanagan et al. 2019). Table 3.1 summarizes some of the studies that have characterized and evaluated vanilla genetic resources for various phenotypic and genotypic traits. In general, many of these studies have focused on screening for *Fusarium* resistance, both in the field and *in vitro*, and on developing methodologies for breeding for resistance. The other major focus for evaluation was assessing the diversity of the four main components of vanilla aroma and flavor within *V. planifolia*. These components had significant genetic variance within *V. planifolia* accessions collected in Mexico (Salazar-Rojas et al. 2012; Herrera-Cabrera et al. 2012; Herrera-Cabrera et al. 2016; Díaz-Bautista et al. 2018). While many of these studies reported differences within and between species and locations, they also concluded that the curing method and production environment had an influence.

Genotypic characterization of the diversity among and within species has been reported in several studies (Table 3.1). Most of these assessments of intraspecific variation found very low levels of genetic diversity within the two cultivated species that were not related to morphological or phenological diversity. The only exceptions in Table 3.1 were reported with the use of ISSR markers in the studies of Ramos-Castella et al. (2017) and Villanueva-Viramontes et al. (2017), the use of microsatellite markers in the study of chemotypes in Herrera-Cabrera et al. (2012), the use of SNP markers (Hu et al. 2019; Chambers et al. 2021) and genomic sequencing (Hasing et al. 2020; Li et al. 2020). These particular studies concluded that within *V. planifolia*, *V. x tahitensis* and *V. pompona*, both within the primary and the secondary centers of diversity, there is untapped genetic diversity. Herrera-Cabrera et al. (2012) found six chemotypes with specific aromatic characteristics associated with specific genome regions, which could be of value for breeding new marketable vanilla products. All the studies that utilized genotypic measures concluded that the use of molecular markers would enhance the identification and use of diversity as well as its conservation.

However, Hu et al. (2019) stated that the molecular tools used in earlier studies had major limitations when used beyond species-level resolution. They concluded that expanding the use of a genomic platform using SNP markers would uncover hidden diversity within the cultivated species for the selection of parents in vanilla breeding programs and for better targeting collection and conservation. By using such a platform, Hu et al. (2019) were also able to identify interspecific hybrids and misidentified accessions, suggesting that the genomic characterization of all vanilla accessions, including those held by botanical gardens, would greatly benefit the conservation, use and exchange of vanilla germplasm. Li et al. (2020) identified a smaller set of SNP markers to detect species-level diversity and hybridization to enhance breeding programs.

Chambers et al. (2021) conducted a genotyping-by-sequencing study including 412 accessions of 27 species

Table 3.1 Characterization and evaluation of *Vanilla* genetic resources for various phenotypic and genotypic traits

Trait	Accessions evaluated	Source of accessions	Reference
Resistance to *Fusarium oxysporum* f. sp. *radicis-vanillae*	New cultivar 'Tsy taitra'	(*V. planifolia* × *V. pompona*) × *V. planifolia* backcross	Grisoni et al. (2009)
	115 accessions of *V. planifolia* and interspecific hybrids	Vanilla Research Station of Antalaha, Madagascar (until 1974)	Dequaire (1976)
	254 accessions of *V. planifolia*, 'Handa' variety	Biological Resource Center (BRC) Vatel, Réunion	Koyyappurath et al. (2015)
	Interspecific hybrids of *V. planifolia* with *V. pompona*		Havkin-Frenkel and Belanger (2011)
	Somaclonal variation in 'Mansa' morphotype of *V. planifolia*		Ramírez-Mosqueda et al. (2019)
Aroma and fatty acid content	30 samples of *V. planifolia* and *V. tahitensis* from 7 production countries		Brunschwig et al. (2009)
Vanillin, p-hydrobenzoic acid, vanillic acid, p-hydroxybenzalde-hyde	Accession of *V. planifolia* and *V. tahitensis* from 7 locations globally		Ranadive (1992)
	25 cultivated and 6 wild accessions of *V. planifolia*	Collections from traditional production fields in Totonacapan Puebla-Veracruz and 6 wild accessions from Oaxaca, Mexico	Salazar-Rojas et al. 2012; Herrera-Cabrera et al. 2012; Her-rera-Cabrera et al. 2016
Nine morphological traits and three phytochemical traits	32 location × species accession for *V. planifolia*, *V. planifolia* cv. 'orejo de burro,' *V. pompano*, *V. insignis* and *V. inodora*	Study sites in Totonacapan Region, Mexico	Díaz-Bautista et al. 2018
Fruit and seed morphology	11 accessions of *V planifolia* (*V. planifolia*, *V. insignis*, *V. inodora*, *V. pompona*)	Benemérita Universidad Autónoma de Puebla, Mexico	Reyes-Lopez et al. 2014
Seed morphology, viability and symbiotic seed germination	*V. rivasii*, *V. calyculata* and *V. odorata*	Valle del Cauca region, Colombia	Alomia et al. 2016; Alomia et al. 2017
DNA content, chromosome counts, and stomatal length	50 accessions of *V. planifolia*	Biological Resources Center (BRC) Vatel, Réunion	Bory et al. (2008)
Genotypic characterization of *V. planifolia* with AFLP markers	100 accessions of *V. planifolia* and other species from the vari-ous regions	Collected from various regions of Mexico, Guatemala and Belize	Lubinsky et al. (2008a)
Genotypic characterization within two cultivated species of vanilla with microsatellite markers	7 accessions *of V. x tahitensis*, 61 accessions of *V. planifolia* and 15 other *Vanilla* species	Biological Resources Center (BRC) Vatel, Réunion	Bory et al. (2008)
Genotypic characterization with RAPD and ISSR markers	13 accessions sampled from plantations	Collected from plantations in Karnataka, Kerala, and Tamil Nadu in India	Sreedhar et al. (2007)
Genotypic characterization of *V. x tahitensis* with AFLP markers	16 morphotypes from French Polynesia		Lepers-Andrze-jewski et al. (2011)
Genotypic characterization within chemotypes of *V. planifolia* with microsatellite markers	25 cultivated and 6 wild accessions of *V. planifolia*	Collections from traditional production fields in Totonacapan Puebla-Veracruz and 6 wild accessions from Oaxaca, Mexico	Herrera-Cabrera et al. (2012)

Trait	Accessions evaluated	Source of accessions	Reference
Genotypic characterization within *V. planifolia* using ISSR markers	20 accessions	Collected from 14 sites in the states of Veracruz, Oaxaca and Quintana Roo in Mexico	Ramos-Castella et al. (2017)
Genotypic characterization with ISSR and ITS markers	88 wild accessions	Collected from natural areas in Yucatan Peninsula, Mexico	Villanueva-Vi-ramontes et al. (2017)
Genomic characterization with SNP markers	112 accessions from 23 species	Tropical Research and Education Center, University of Florida, USA	Hu et al. (2019)
Characterization of vanillin pathway and bean quality with genomic sequencing	4 species	Tropical Research and Education Center, University of Florida, USA	Hasing et al. 2020
Characterization of species and species hybridization in seedlings	16 species and hybrid progeny	Tropical Research and Education Center, University of Florida, USA	Li et al. (2020)
Genotyping-by-sequencing diver-sity analysis	412 accessions of 27 species	University of Florida, USA; Unidad de manejo para la conservación de la vida silvestre Xochitlcall SEMAR-NAT, Mexico; Langebio Centro de Investigación y Estudios Avanzados, Mexico; Cavite State University, Philippines; Belize National Herbarium, Belize; Cor-ridgeree Belize ltd., Belize; Universidad de los Andes, Colombia; Jardin Botanico Lankester, University of Costa Rica, Costa Rica; Instituto Nacional deInvesti-gaciones Forestales, Agrícolas, y Pecuarias (INIFAP); Marie Selby Botanical Gardens (USA).	Chambers et al. (2021)

conserved in nine different collections, including 169 accessions of *V. planifolia* from different countries. They found that three types of *V. planifolia* can be distinguished based on the results of PCA, STRUCTURE and phylogenetic analysis and that type 2 is the closest to *V.* x *tahitensis*. Their results also confirmed the hybrid origin of *V.* x *tahitensis* and suggest that this hybrid may have originated in Belize.

Crop improvement for vanilla

Fusarium oxysporum forma *specialis radicis-vanillae* (Forv) is the main causal agent for the most signif-icant disease that affects vanilla production glob-ally, fusarium root rot. In Madagascar in the 1950s, *Fusarium* caused losses of 25% of average production (Grisoni 2021). As the disease can only be controlled by growing resistant varieties, the low level of genetic diversity in the Indian Ocean region led to a need to diversify the germplasm base. A vanilla hybridization program was initiated in Madagascar in 1944 and continues today in the national research institute, Centre National de la Recherche Appliquée au Dévél-oppement Rural (FOFIFA). Vanilla can be bred through sexual reproduction by germination of the seeds *in vitro*. This approach has been used to develop selfed populations as well as for interspecific hybridization. Variety development has also been accomplished via mutagenesis in Madagascar (Dequaire 1976). One other alternative is to utilize polyploidization to select within an autotetraploid (Grisoni 2021).

Grisoni (2021) reviewed the history of the vanilla breeding program in Madagascar, whose objectives were to develop new varieties with aromatic fruits, resistance to *Fusarium*, indehiscent fruits, earliness and hardiness. The first phase of the breeding program focused on development and selection from selfed progenies of local varieties and intercrosses with various accessions of *Vanilla* species acquired through collection or exchange. They were able to produce fertile hybrids only with accessions from the Amer-icas. No resistance or acceptable quality was found in these progenies. Therefore, in the second phase, the focus shifted away from selfing and onto inter-specific hybridization species from the Americas. The third phase began with an inventory of all the inter-specific hybrids. These consisted of first-, second- and third-generation hybrids between five different species and *V. planifolia*. These species included *V. x tahitensis*, *V. pompano* and some taxonomically poorly identified accessions. The focus of the third phase was not on new hybridization but only on maintenance, selection and distribution of the existing inventory of hybrids.

Grisoni (2021) also reviewed the selection, testing, release and adoption of new varieties from the Mada-gascar breeding program. Field tests were established in 1986–87 in 10 localities throughout the SAVA region of Northern Madagascar. Two of these hybrids were selected for release by FOFIFA in 1995. One hybrid had high vanillin content and early fruit set, but it was not very vigorous and was susceptible to *Fusarium*, so it was not widely grown. The other hybrid had good resistance to *Fusarium* but low levels of vanillin; it was also not grown, and the curers did not favor it either. However, this hybrid was introduced into Costa Rica, where it was multiplied and tested, and is now widely grown.

Although the Madagascar breeding program released only two varieties after 45 years, the breeding effort required the development of important techniques, including for seed germination *in vitro* and reproduction and acclimation of tissue culture plants (Grisoni 2021). Breeders had to deal with difficult acquisition and cultivation procedures for germplasm with very little knowledge of the taxonomic and genetic relationships. They also had to cope with inbreeding depression in the selfed progenies and with sterility in the wide hybrids that had not been previously encountered. They had to develop phenotyping methods to screen for *Fusarium* resistance, quality parameters and other traits. Finally, they had to adapt to the length of the reproductive cycle, which is about 7 years. Therefore, although the breeding program did not make as many gains as hoped, it did establish procedures and knowledge for future breeding. It also established an *ex situ* genetic resources collection that included accessions acquired from other collections and unique interspecific hybrids. These are important genetic resources for the future breeding of vanilla.

Grisoni (2021) also identified key needs for future breeding programs, including the need for improved *in vitro* techniques, improved screens for *Fusarium* resistance, new data management technologies and the application of molecular tools. Li et al. (2020) concluded that future breeding in vanilla will benefit from better understanding of the genetic basis of traits and selection of promising genotypes with the application of molecular tools now being developed, such as genomic sequencing. Some of the key traits identified for improvement include the following (Grisoni 2021):

- Increased productivity potential
- Resistance to Fusarium root rot, Phytophthora, and anthracnose
- Increased rate of self-pollination
- Greater adaptation to hotter and drier growing conditions
- Changes in phenology, such as rate of ripening or plant morphology
- Reduced premature flower abortion
- Non-shattering pods
- Longer pod with thin skin and good color and luster
- Quality components such as vanillin content and other aromatic compounds, flavor, and aroma
- Increased and diverse fragrance with new unique aromatic compounds

The diversity present in at least 45 *Vanilla* species offers potential for the improvement of cultivated vanilla or for direct use as unique flavoring or fragrances. Bory et al. (2010) described the history of interspecific hybridization for breeding in *V. planifolia*. The use of the various *Vanilla* species for genetic improvement of the vanilla crop was intensively reviewed by Flanagan et al. (2019), who found that, generally, orchids have high interspecific compatibility. Andriamihaja et al. (2020) concluded that species found in Africa and Asia could be sources of resistance to biotic stresses and improved tolerance to abiotic stresses to improve adaptation of vanilla to warmer, drier conditions.

Jimenez et al. (2017) developed bioclimatic profiles for seven *Vanilla* species in Mexico, which could be used to assess genetic diversity and to target species for use in crop improvement programs. *Vanilla odorata* is found at cooler high altitudes so could be a source of increased tolerance to lower temperatures. *Vanilla insignis* was found to be more tolerant than *V. planifolia* to temperature extremes, heavy soils and flooding, as well as being resistant to pathogens (Soto-Arenas and Dressler 2010); *V. cribbiana* could be a source of resistance to drought and diseases. Interspecific hybridization is being used by breeders at several institutions (University of Florida, USA; BRC Vatel, Réunion; Universidad Veracruzana, Mexico; Pontificia Universidad Javeriana Cali, Colombia).

Exchange of vanilla genetic resources

Careful records on the origin of accessions must be kept to facilitate exchange and use in compliance with the Convention on Biological Diversity and any other relevant regulations (Grisoni et al. 2007). In Mexico, *V. planifolia* is subject to special protection, according to the Official Mexican Standard (NOM-059-SEMARNAT-2010) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES-2015). Currently, international exchange from Mexico also requires adherence to the access and benefit-sharing terms of the Nagoya Protocol. Globally, all species of the family Orchidaceae are listed in Appendix I or II of CITES-15. Appendix II, in which *Vanilla* species are included, lists species that are threatened by extinction if international trade is not managed. However, fruits, and parts and derivatives thereof, of naturalized or artificially propagated plants of the genus *Vanilla* are not included (cites.org/eng/app/appendices.php). Thus, only the trade of wild-sourced *Vanilla* species requires an export permit or re-export certificate, which are granted only if the trade will not be detrimental to the survival of the species in the wild.

Grisoni (2021) discusses the legal status of the unique breeding material developed by FOFIFA. These hybrids have been widely disseminated to producers in Madagascar and internationally to researchers and others for more than 25 years. The author concluded that the best option for the exchange of these genetic resources was for Madagascar to add these voluntarily to the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) to facilitate access and benefit sharing through the standard material transfer agreement (SMTA).

To conserve and use genetic diversity effectively, the plant health of the accession in *ex situ* collections must be carefully managed. CyMV has spread in Madagascar, derived from virus-contaminated accessions that had been previously imported for use in research and breeding programs (Grisoni 2021); this has created a need to eliminate the CyMV virus from field collections and from all accessions *in vitro* to reduce risks to production in Madagascar as well as to facilitate the global exchange of germplasm.

In situ and *circa situm* conservation of vanilla

The genetic resources of *Vanilla* species in the wild, such as *V. planifolia,* are made up of rare and infrequent populations consisting of only a small number of individuals. These populations are increasingly under threat due to high human pressure (deforestation and collection of plants for establishment of plantations) (Bory et al. 2008a; Flanagan and Mosquera-Espinosa 2016; Watteyn et al. 2020). Large areas of vanilla's native habitat are protected by law (e.g. 25% of the land in Colombia is in national parks or autonomous indigenous territories) (Flanagan et al. 2019). However, given that endangered *Vanilla* species are small and widely dispersed, protected regions are not big enough for conservation purposes, which means monitoring and management (e.g. assisted migration) are necessary (Flanagan et al. 2019). *In situ* conservation is also essential to preserve ecological interactions, including with pollinators and microbiomes that have not yet been described (Flanagan et al. 2019). Villanueva-Viramontes et al. (2017) concluded that existing wild vanilla populations must be conserved with a healthy population size, as cross pollination is more important in the wild in the Yucatan Peninsula.

Circa situm conservation involves safeguarding the genetic diversity of a species through its cultivation in an agricultural system, such as agroforestry systems, in the range of the appropriate geographic distribution for the species. Dawson et al. (2012) offered practical suggestions for actions that will promote and sustain *circa situm* conservation with positive impacts both on the biodiversity of the focal species and on the ecosystems. Two key issues for the future sustainability of *circa situm* conservation were the need to balance conservation with intensifying production to meet market opportunities and the challenges of climate change. To address the impact of climate change on local conservation systems, Dawson et al. (2012) suggested that local diversity would need to be migrated to localities where it is better adapted, as well as managing the introduction of new, improved germplasm to reduce any risk of eroding the genetic diversity being conserved.

In Colombia, various initiatives are exploring the sustainable inclusion of native *Vanilla* species in the traditional agroforestry systems of forest-dependent communities (personal communication, Nicola Flanagan, Pontificia Universidad Javeriana – Cali, Jan 25 2021). Managing the genetic diversity maintained within the crop might require the use of diverse and quality planting material from newly established plant material enterprises or community conservation gardens. In countries such as Colombia, where majority of native *Vanilla* species occur in autonomous territories, it is essential to ensure access and benefit-sharing protocols are fully implemented.

Conservation of this diversity is a challenge because of its complex nature, as indicated by the presence of chemotype variation in the Totonacapan region in Mexico (Herrera-Cabrera et al. 2012; Ramos-Castella et al. 2017). Herrera-Cabrera et al. (2012) described the situation as follows (page 49):

> "Today, there is more diversity in production systems than in natural landscapes. For this reason and because conservation of *V. planifolia* articulates social, economic and biological elements, because the growers are the agents of conservation, because variation in vanilla germplasm is product of a process of domestication, because its geographic distribution is associated with the presence of traditional systems of production, and because the Totonacapan region is the probable center of diversification of the species, it seems that the best alternative, theoretically and practically, is to develop an integrated conservation strategy for the primary genetic pool of vanilla in which *circa situm* actions play a key role."

Furthermore, the security of conservation of each chemotype is related to its commercial value to stakeholders (Herrera-Cabrera et al. 2012). As a result, three of the chemotypes were being conserved through use, but chemotypes that are less widely cultivated require interventions to secure their conservation in traditional fields or in *ex situ* collections. Overall, conservation of genetic diversity of vanilla chemotypes depends upon the future of cultivation in traditional systems, of the culture of the Totonac peoples, and of traditional production and processing. Therefore, vanilla *circa situm* conservation will require strategies and policies that have a long-term focus on developing and strengthening livelihoods in the rural communities that manage these genetic resources. Lubinsky et al. (2008c) concluded that conservation of vanilla in traditional systems requires careful management, with the introduction of new planting material from other production areas, and may require a complementary *ex situ* collection to manage the risk of diversity loss caused by farmers shifting to improved varieties or by the negative impacts of climate change.

Ex situ conservation of vanilla

Ex situ conservation is a useful strategy to preserve vanilla genetic resources securely (Bory 2008; Menchaca and Lozano 2018) as a complement to *in situ* and *circa situm* conservation. It can be achieved by establishing germplasm banks of living plants, *in vitro* cultures, seeds, and cryopreserved meristems or immature seeds. *Ex situ* collections of living plants are either conserved in shade houses or in the field in tropical climates or under controlled conditions in conservatories or greenhouses in temperate climates. In Réunion, for example (Grisoni et al. 2007; Grisoni et al. 2011), the collection is maintained as healthy living plants grown on wooden frames in an insect-proof shade house. The plants are sprayed regularly to manage the major diseases and vines are checked annually for viruses. These accessions are also conserved in *in vitro* cultures established from axillary buds. A key need for future conservation is the availability of more secure approaches for medium- and long-term conservation, such as cryopreservation (Grisoni et al. 2007; Grisoni et al. 2011).

Field conservation

Ex situ conservation of living plants is time and labor intensive, as plants have to be monitored and treated for pathogens, vines trained on supports, and plants replaced periodically. These living collections are highly vulnerable to biotic threats, such as *Fusarium* and CyMV, and natural disasters such as flooding, cyclones and hurricanes. Furthermore, in the past, staffing changes, funding shortfalls, political instability and natural disasters have led to neglect and abandonment of collections, resulting in loss of genetic diversity in several instances, such as the large collection of Benemérita Universidad Autónoma de Puebla (BUAP) in Puebla, Mexico (Menchaca and Moreno 2020) and the large collection of FOFIFA in Antalaha, Madagascar, which was established in the mid-1900s (Grisoni et al. 2007; Bory et al. 2008a; Grisoni 2021). In the past, these were the two largest *ex situ* collections of vanilla in the world.

Orchid plants, including *Vanilla* species, are also conserved in botanical gardens, which have a long history in plant exploration, plant propagation and establishment, scientific research, public awareness, advocacy and conservation. Botanical gardens have played a significant role in the dissemination of cultivated vanilla globally and have contributed to research on taxonomy and propagation (Lubinsky et al. 2008c). However, while botanical gardens hold large number of species overall, especially wild species, they tend to have very little intraspecific diversity for most species (O'Donnell and Sharrock 2018). As a result, plants conserved in botanical gardens' collections will not match the diversity held in crop-specific *ex situ* collections, but they are valuable for educating the public on the origin of their food, the diversity of plants and the conservation of potentially valuable traits, particularly in crop wild relatives. The costs of maintaining collections are high under the controlled conditions required for *Vanilla* species, including adaptation to a tropical climate and routine maintenance with periodic propagation and training of the vines. Therefore, each botanical garden usually holds only a few vanilla plants. However, botanical gardens could be important repositories for *ex situ* conservation of vanilla in Colombia (Flanagan and Mosquera-Espinosa 2016).

In vitro conservation

Conservation of vanilla in *in vitro* cultures is being used to complement field collections and to develop virus-free planting material, including in Réunion (Grisoni et al. 2007). Divakaran et al. (2006) reported on protocols for both slow growth methods and cryopreservation of meristematic tissue or protocorms for securing long-term conservation. They also identified routine *in vitro* protocols that can be used for mass propagation and safe germplasm distribution as a component of the long-term conservation of *V. planifolia* and other species.

In vitro conservation requires a high initial investment in an appropriate laboratory. Once well established, *in vitro* collections could be managed securely with relatively little need for labor, time or space, and relatively independently of climate conditions compared to field collections. For example, this was achieved at the Universidad Veracruzana, Mexico, initially funded by the Secretary of Agriculture, Livestock, Rural Development, Fisheries, and Food (SAGAPRA) in Mexico through the Mexican Vanilla Network (Menchaca and Lozano 2018). The establishment of an *in vitro* culture laboratory could also allow for the propagation of accessions, hybrids, or varieties in a high-throughput manner (Halim et al. 2017).

Cryopreservation of shoot-tips is considered a safe alternative for the long-term storage of genetic resources of species that cannot be conserved using traditional seed banking (Cruz-Cruz et al. 2013). With improved preparation protocols and several months for recovery, up to 33% of *in vitro* cultures of *V. planifolia* could be regenerated after being cryopreserved in liquid nitrogen in the vapor phase at −196 °C (Hernández-Ramírez et al. 2020). This protocol should be tested and extended to other *Vanilla* species.

Seed conservation

Vanilla is generally propagated clonally by cuttings, although propagation by seeds is possible. However, vanilla seeds rarely germinate *in vivo* due to biological barriers and a dependence on symbiotic fungi (Dequaire 1976; Porras-Alfaro and Bayman 2007). Grisoni (2021) described the development of *in vitro* approaches to optimize the germination of seeds through improved embryo culture and mycorrhizal fungi (genus *Rhizoctonia*) (Dequaire 1976; Porras-Alfaro and Bayman 2007; Divakaran et al. 2010) or the germination of immature embryos (Menchaca et al. 2011). Seeds are used for the development of hybrids and selfed segregating populations for vanilla breeding. Seeds are an effective method to move germplasm from one collection to another more safely with relatively low phytosanitary risk (Pearson et al. 1991).

Seaton et al. (2018) described protocols for the collection and *ex situ* conservation of orchids through seed and pollen as a complement to *in situ* and *ex situ* conservation as living plants. They concluded that orchid seeds could be conserved for decades in the right conditions.

Another promising approach for the long-term conservation of orchids is the use of synthetic seeds that are somatic embryos, protocorms or meristematic tissue that are artificially encapsulated and can be germinated into complete plantlets. Divakaran et al. (2006) compared conservation of synthetic seeds of cultivated vanilla at low temperature or cryopreserved. Gantait and Mitra (2019) concluded that synthetic seed had the potential to be used for long-term conservation, mass propagation and safe germplasm exchange. However, more research is needed to improve the technology of synthetic seeds for vanilla.

Integrated approaches to conservation

The challenges facing *ex situ* conservation of collections, such the loss of genetic diversity due to natural disasters, insecure funding and pathogens, could be met using an integrated approach, where accessions held in the field or greenhouse are duplicated *in vitro* (Grisoni et al. 2007; Flanagan and Mosquera-Espinosa 2016). The use of cryopreservation of vanilla shoots or synthetic seeds should be expanded. In the future, it might also be possible to conserve seeds in addition to the other approaches. A combination of options will increase the health and security of conservation, increase opportunities to mass-propagate accessions on demand, and enhance the safety of germplasm distribution.

Herrera-Cabrera et al. (2012), Flanagan and Mosquera-Espinosa (2016) and Watteyn et al. (2020) proposed integrated strategies for the conservation of vanilla genetic resources for Mexico, Colombia and Costa Rica, respectively, involving *in situ*, *circa situm* and *ex situ* conservation methods. Andriamihaja et al. (2020) supported the implementation of the integrated strategy described in Flanagan and Mosquera-Espinosa (2016) for the conservation of vanilla species (section *Tethya*) in the Indian Ocean zone.

Watteyn et al. (2020) suggested a joint land sparing and land sharing approach (SPASHA) in Costa Rica to protect wild vanilla populations, their pollinators and the associated microorganisms inside the forest, while using adjacent areas for vanilla production in agroforestry cropping systems with natural interactions kept as intact as possible. They concluded that implementation of SPASHA would result in the creation of diverse landscapes with the production of high-value certified vanilla on degraded lands and a sustainably managed protected natural forest. The application of SPASHA would enhance the areas' environmental and economic value and offer alternative income streams for local communities.

Flanagan and Mosquera-Espinosa (2016) outlined an integrated strategy for conservation of *Vanilla* species that included *in situ*, *ex situ* and *circa situm* conservation that worked with local communities to facilitate sustainable conservation through use. They identified number of high-priority research needs to fill significant gaps in knowledge for enhanced long-term conservation, addressing production constraints and adding value for the various native species with their unique aroma profiles. Increased research on the taxonomy, distribution, ecological characteristics, and organoleptic traits of native *Vanilla* species could be used to protect the species and ensure they are included within *in situ* protected areas. The associated mycorrhiza and other microbiome components also need to be conserved. *Circa situm* conservation with community-based cultivation and community-based *ex situ* collections would encourage production of certified *V. planifolia* in the diverse forest production systems or production of other wild species for new markets for vanilla.

Illustration of Vanilla planifolia, Curtis's Botanical Magazine, 1891.
Illustrators: Matilda Smith and John Nugent Fitch

4 SUMMARY OF THE BACKGROUND REVIEW

Vanilla planifolia, the main species cultivated to obtain vanilla, is a robust vine from which the fruit is harvested and processed. Global vanilla production is concentrated in five countries, with the vast majority produced from *V. planifolia* in Madagascar. Vanilla has a long history as a key ingredient in numerous food and non-food products. Vanilla is a very important source of income for many smallholder farmers in tropical areas of the world, but efficiencies in both production and market systems have led to an unsustainable international market system. Vanillin from vanilla pods accounts for only about 1% of the market, but demand for real vanilla is expected to increase steadily for the food, fragrance, and medical sectors.

Vanilla production requires similar temperatures, relative humidity and annual rainfall amount and distribution to those found in the lowland tropics. The plant is sensitive to dry spells, heat waves and extreme winds such as cyclones, hurricanes, and tropical storms. Vanilla production and processing are highly specialized skills that require considerable experience. Many buyers are introducing initiatives to reduce risks, increase quality and encourage sustainable production, while also sustaining the supply of real vanilla. In general, efforts to increase supply to meet growing demand have proven to be a slow process that is being further hampered by climate change. The suppliers and consumers of real vanilla are also facing greater costs for the raw ingredient, fluctuations in availability and quality, and the increased availability of natural alternatives. Thus, the current global situation for vanilla production and consumption is vulnerable, with many constraints that need to be addressed; however, there are also new market opportunities.

The total number of species in the *Vanilla* genus remains unclear, but the highest numbers of species are found in Central and South America (62 species). Currently, three species of vanilla are cultivated as the sources of natural vanilla pods: *V. planifolia*, *V. x tahitensis* and *V. pompona*. The center of origin of *V. planifolia* is likely southwestern Mexico, through Central America to northwest South America. However, due to the dispersal of cultivated *V. planifolia* and *V. x tahitensis* throughout the world, there are potentially secondary centers of diversity in the Indian Ocean region and in French Polynesia.

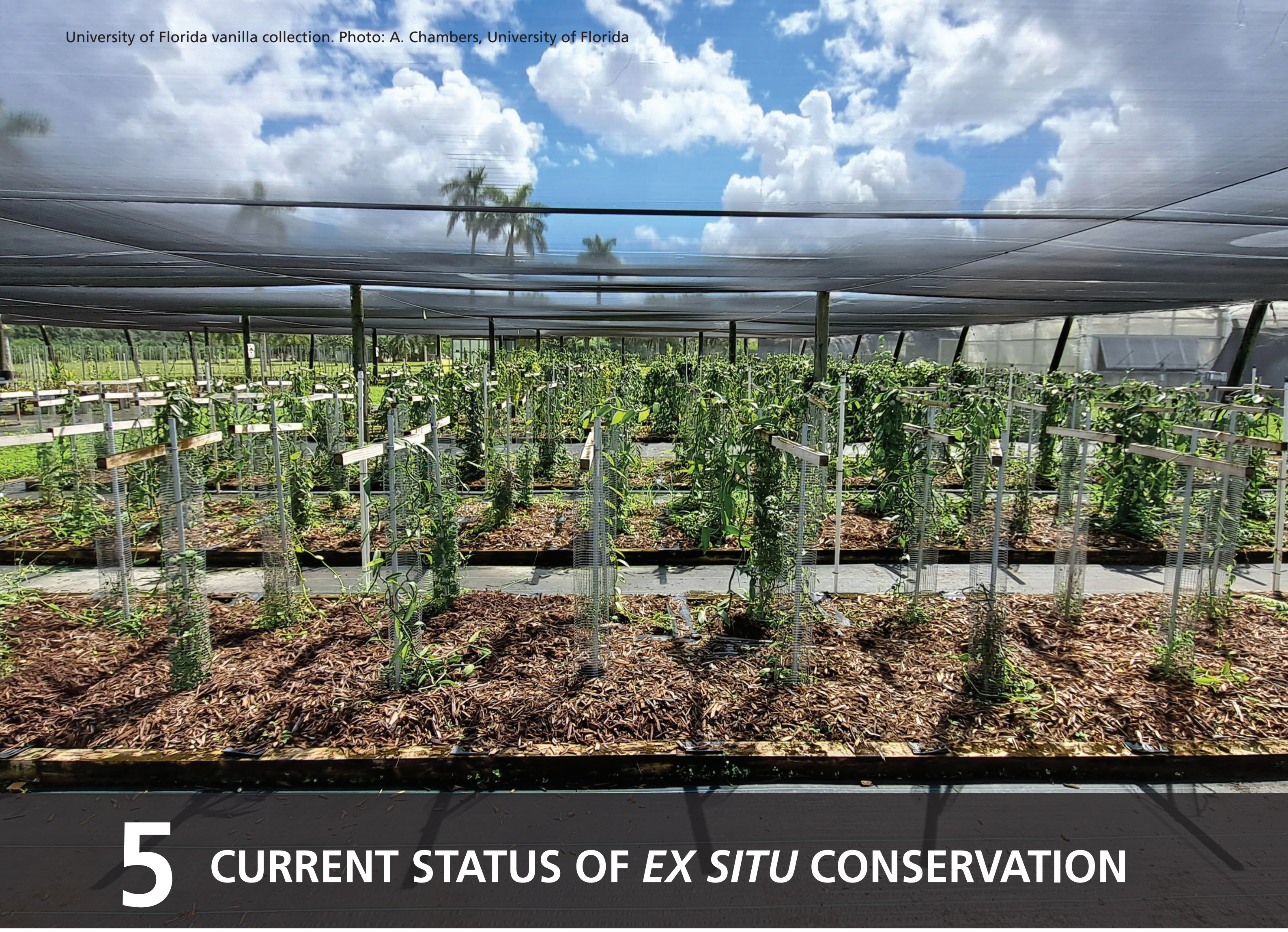
There are no consistent morphological differences between wild and cultivated *V. planifolia*. The historical pattern of dissemination and cultivation has led to an extremely narrow genetic base of the crop, and this genetic uniformity makes global vanilla production extremely susceptible to diseases and pests. To ensure the future use of vanilla, it is therefore essential to genetically diversify the crop, to improve disease and pest tolerance or resistance, increase tolerance to changing environmental conditions, and improve the quality and yield of currently used germplasm. Vanilla breeding has involved selection within selfed progeny or hybrids developed by crossing two *V. planifolia* parents or with other *Vanilla* species by using *in vitro* culture of the immature seeds. Diversity present in section *Xanata* offers potential for direct use as unique flavoring or in fragrances and could provide valuable parental material to introgress genes for improving productivity, disease resistance, tolerance to abiotic stresses, and components of aroma and flavor quality.

As a crop in both traditional plantations or eco-plantations, vanilla can support or enhance biodiversity. It also offers a source of sustainable production and income for smallholders that manage land near protected forests. In addition, several *Vanilla* species have unique fragrance and aroma profiles or medicinal uses that have commercial value, and so have potential for cultivation along with *V. planifolia*.

The future production and use of vanilla are dependent upon diversification within species, between species, within agroforestry cropping systems, and within international, national, and local markets. Achieving this will require greater diversification of products and markets for vanilla in producing countries. A key element for a sustainable future for the sector is the secure conservation and use of vanilla genetic resources today.

As seen in the literature review, the genetic diversity of vanilla is recognized to be a critical resource both for securing future supply and for enhancing specific quality characteristics. While there have been efforts to develop integrated strategies to secure vanilla genetic resources within key countries, relatively few publications address the history, status and future needs of vanilla *ex situ* germplasm collections. The genetic resources of vanilla are complex, and plant populations are highly vulnerable to genetic erosion from deforestation, land-use change, pests and diseases, climate change and natural disasters. The loss of an accession or plant conserved *ex situ*, *in situ* or *circa situm* might mean the loss of a key source of future improvement of vanilla production or quality. Given these threats, safeguarding vanilla diversity over the long term and enhancing its use will require a concerted global effort to conserve diversity nationally or internationally using a range of *ex situ* approaches, including field collections, *in vitro* methods and cryopreservation of plant material. There is also an urgent need to combine *in situ*, *ex situ* and *circa situm* approaches in an effective integrated strategy that considers conservation, market diversification, rural development, and access and benefit-sharing agreements.

University of Florida vanilla collection. Photo: A. Chambers, University of Florida



5 CURRENT STATUS OF *EX SITU* CONSERVATION

Composition of *ex situ* collections

Annex II lists the number of accessions conserved globally and the number of institutions holding them for each *Vanilla* species conserved *ex situ*, based upon a consolidated database compiled from FAO WIEWS, GBIF and BGCI. For this strategy, a questionnaire was sent to 45 key collection holders that had been identified from global databases, literature searches and contacts provided by experts. The questionnaire was completed by 18 collection holders, listed in Annex III. Eleven of the respondents were from the Americas, five were from Europe and two were from the Indian Ocean region. Global sampling of institutions was therefore adequate, although a major gap in the survey is the collection held by the Indian Institute of Spice Research. Globally, the top 49 institutions consist of 34 botanical gardens, nine government institutions, four universities and two private collections. By comparison, survey respondents comprised seven botanical gardens, three government institutions, five universities and three private collections.

Annex II provides the numbers of institutions and accessions for respondents to the survey of *ex situ* collection holders of vanilla. Survey respondents accounted for 62% of the total number of accessions conserved in *ex situ* collections globally. According to combined data from the global databases, a total of 49 institutions conserves six or more accessions; in the survey, all 18 respondents reported holding six or more accessions. Overall, despite some significant gaps, as mentioned above, the survey respondents can be seen as a representative sample of the existing global system.

Unfortunately, the accession-level reporting in the global databases does not fully capture the current global composition of collections. In particular, the composition of the large collection of BRC Vatel in Réunion is not reported in any of these global databases. While the BUAP collection of 192 accessions of *V. planifolia* and the FOFIFA collections of 32 accessions of *V. planifolia* are reported in the FAO database, both these collections are known to have lost many of their accessions. In total, 1,818 accessions of *Vanilla* species are recorded as being conserved at 221 institutions, including national genebanks, universities, botanical gardens and private collections.

The number of species and accessions conserved *ex situ* were compared for each section of the two subgenera of the *Vanilla* genus, globally and for the respondents to the questionnaire (Table 5.1). According to the global databases, 65 species have no accessions conserved *ex situ*. Survey responses revealed that a further 10 species are not conserved in their collections. More than 80% of the accessions conserved globally or by survey respondents were from species in section *Xanata*. There are very few accessions of species in section *Membranacea* conserved in *ex situ* collections. Within *Tethya*, only 36% of the accessions conserved globally were held by survey respondents.

A significant number of species (30) have very few accessions conserved *ex situ* (Annex II). More than 75% of the accessions conserved globally and by survey respondents are from *V. planifolia*, *V. x tahitensis*, *V. pompona*, *V. odorata*, *V. insignis* and *V. phaeantha* in section *Xanata,* and originate from Central/South America. There are seven species within section *Tethya* with at least 10 accessions conserved globally, and at least five accessions conserved by survey respondents. Thus, only a few species are represented widely across *ex situ* collections.

The survey respondents were asked to indicate the number of accessions collected from farmers nationally, collected from natural areas nationally or outside the country, or known to be duplicates from other collections. The number of accessions from the various sources was analyzed (Figure 5.1). Overall, majority of accessions are in collections made from farmers' fields or natural areas in the country of the collection holder. For *V. planifolia* and *V. x tahitensis,* accessions were collected mainly from farmers' fields in the country or were sourced from other collections. As expected, wild species in *Xanata* had more accessions collected from natural areas, both within and outside the country. For accessions in *Tethya*, most of accessions were from other collections, which indicates that the survey respondents are conserving a small number of unique accessions for the 23 species in this section.

For some species, there are potentially unique accessions collected by an institution nationally and locally but not shared or duplicated with others. To further access the impact of duplication of accessions between institutions, the survey asked each institution "To what extent do you consider the vanilla accessions in your collection to be unique and not duplicated extensively elsewhere (excluding safety-duplication)?". An accession would be considered 100% unique if it was an original collection and was not considered duplicated by any other *ex situ* collection holders, even other farmers in the locality. An accession would be considered 0% unique if it was duplicated extensively in other institutions or with other farmers. An accession would be considered as duplicated from 1–99% depending upon the source of the acquision, either

Table 5.1 Numbers of species and accessions conserved by 221 institutions in global databases and by the 18 institutions that responded to the questionnaire.

	Total no. of species	No. of species conserved (% of total)	No. of accessions	No. of species conserved	No. of accessions
Section		**Global**		**Survey**	
Xanata	38	18 (47%)	1614	17	1013
Tethya	62	31 (50%)	314	23	112
Membranacea	18	5 (28%)	18	4	9
Total	**118**	**53 (45%)**	**1946**	**43**	**1134**

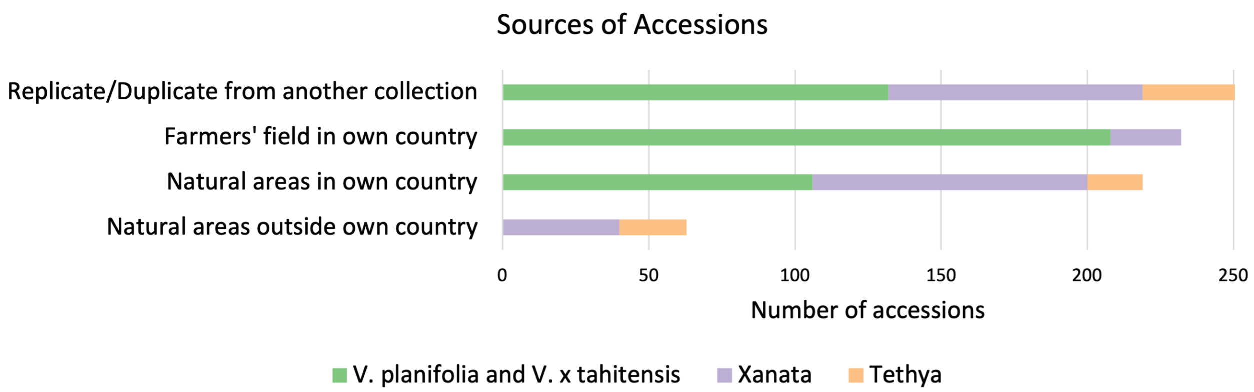


Figure 5.1 Sources of accessions held by survey respondents for the cultivated species *V. planifolia* and *V. x tahitensis*, other species in section *Xanata*, and *Tethya* species

from specific institutes, localities, or samples of a population. Thus, institutions were asked to access the degree of duplication for accessions in their collection as a proxy for uniqueness. Accessions that are only conserved by one or a few institutions are more at risk of genetic erosion or loss. Species with few accessions that are extensively duplicated could also be at risk of genetic erosion in its natural habitat given the limited diversity conserved in *ex situ* collections. Across all species, two institutes reported conserving only accessions that are unique to their collection while seven institutes mainly conserve unique accessions. Conversely, two institutes conserve no unique accessions while five were conserving unique accessions of only a few species.

Figure 5.2 shows respondents' assessments of the uniqueness or the degree of duplication of accessions in their collections for five species. For *V. planifolia*, very few accessions are conserved in only one collection. This finding is surprising given that a high proportion of these accessions were collected from farmers' fields and natural areas within the country; however, it could be an indication of the limited diversity of varieties available to producers. Overall, there is more duplication of accessions of two cultivated *Vanilla* species than of wild species; this is because most of the respondents' conserve diversity acquired from others or because of a lack of diversity in farmers' fields. The lack of diversity of certain species and low levels of duplication of accessions across collections indicate that global conservation of vanilla genetic resources is not secure, which has implications for the actions that need to be taken.

Overall, the respondents indicated that they had only lost about 313 accessions. Two institutions indicated that they had repatriated or re-collected nine accessions. Sixteen of the 18 respondents indicated that, over the past 10 years, they had collected or acquired from other collections a total of 1,181 accessions. Therefore, despite a significant focus on closing gaps in vanilla collections, many gaps remain. Survey respondents noted that their priorities included gaining a better understanding of the diversity in their collections and of the species of unidentified accessions, as increasing their knowledge of their collections would enable them to clarify the gaps. Some respondents also identified a need to increase the within- and among-species representation from farmers' fields and natural areas in their country, and to access greater diversity of *V. planifolia* from Mexico/Central America and *V. x tahitensis* from the Indian Ocean region.

Gaps in diversity

Globally, there are 61 *Vanilla* species for which no accessions are conserved (Table 5.2). All the species in section *Membranacea* are held in no or very few collections (five or fewer), as are more than three-quarters of the species in *Xanata* and *Tethya*. Overall, 11 species are conserved in more than 10 institutions: *V. planifolia*, *V. x tahitensis, V. pompona* and *V. insignis* from section *Xanata*; and *V. imperialis, V. madagascariensis, V. aphylla, V. barbellate, V. roscheri, V. phalaenopsis* and *V. polylepis* from section *Tethya*. Therefore, overall, most *Vanilla* species are not securely conserved in *ex situ* collections glob-

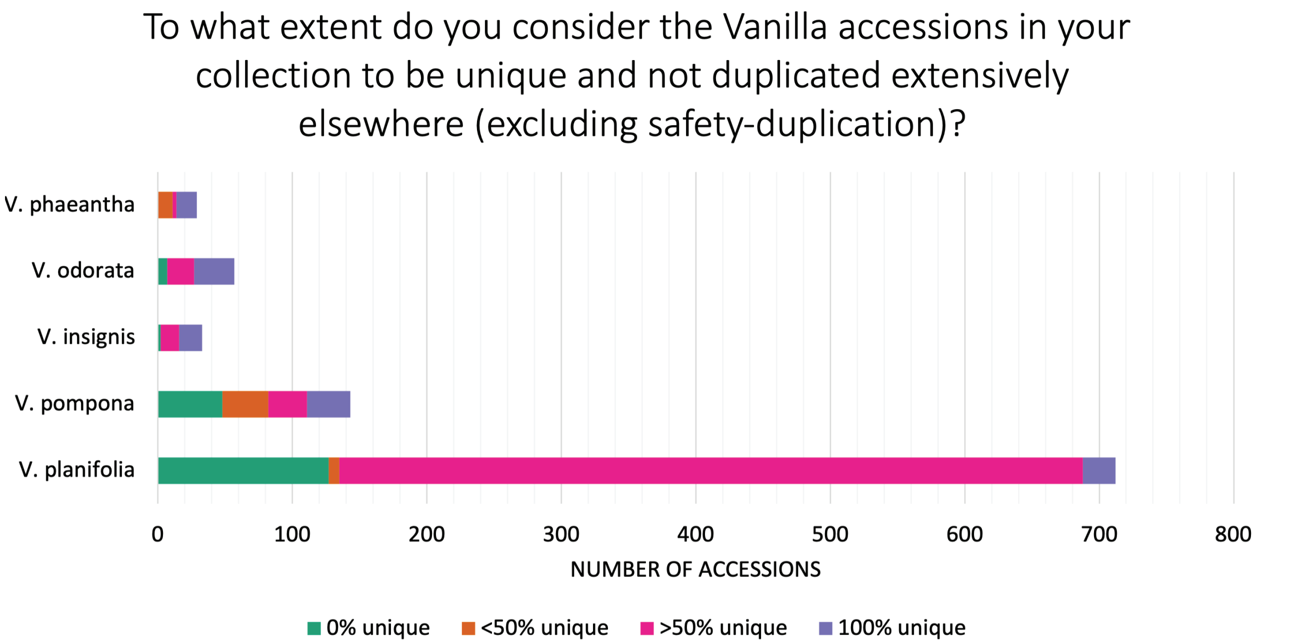


Figure 5.2 The number of accessions for five species that are considered by the institute holding them to be 0%, less than 50%, more than 50%, or 100% unique and not duplicated extensively by other institutions.

ally as many institutes are conserving the same or very closely related accessions.

CIAT (2020) provide a comprehensive assessment of the security of conservation of wild species in *ex situ* collections and conserved *in situ* in parks, reserves and other official protected areas. Using publicly available data, they calculated indicators for *ex situ* and *in situ* conservation, with values ranging from 0 (no conservation) to 100 (highest level of conservation). In general, they concluded that about 3% of the species assessed were well conserved in *ex situ* conservation, and 41% in *in situ* conservation. Table 5.3 gives the results of the CIAT (2020) assessment for a small number of important *Vanilla* species. For seven of these species, action is urgently required, as there is no *ex situ* conservation. For all the species, the assessment found that *in situ* conservation status is much higher than *ex situ*, although that is likely due to the low level of reporting of accessions conserved *ex situ* in global databases used in the study. The researchers concluded that "Urgent action is currently needed to improve the conservation of the diversity of the world's useful wild plant species," including the genus *Vanilla*. The results reported in Annex II, Table 5.1 and Table 5.2 agree with the poor state of *ex situ* conservation for most of the species included in Table 5.3.

Only 11 of the 118 *Vanilla* species (Table 5.4) have been assessed for Red List status (IUCN 2020). Nine of these 11 species are native to Central and South America; of the other two, *V. phalaenopsis* originates from the Seychelles and *V. somai* from Taiwan. All the *Vanilla* species included in Table 5.4 are affected by illegal and uncontrolled collection (Wegier et al. 2020). Furthermore, most species have a narrow area of occupancy, ranging from 24 km² (*V. phaeantha*) to 200 km² (*V. odorata*) with few highly localized populations. In general, *Vanilla* individuals are rarely found in the wild (Soto-Arenas and Dressler 2010) and often only a single individual is found at a collection site (Flanagan and Mosquera-Espinosa 2016). As shown in Table 5.4, all but two of the species are endangered or critically endangered; this includes the main cultivated species, *V. planifolia*, and six wild species in section *Xanata*. Conservation status assessment for other species is an urgent priority. It is important to take into consideration the highly dispersed nature of populations of these species when determining conservation priorities.

Activities that threaten species classified as "endangered" are illustrated by the case of *V. insignis*, for which habitat quality and extent are being reduced by land-use change, especially for agriculture, construction of large dams and urbanization. The Mexican population of *V. cribbiana* is an example of a critically endangered species in continuous decline due to intensified illegal collection and habitat destruction (Hernández et al. 2020). Urgent actions required to

Table 5.2 Number of species conserved by 0, 1–5, 6–10, 11–20 and more than 20 institutions, by section.

	Number of Institutions				
Section (total no. of species)	**0**	**1–5**	**6–10**	**11–20**	**>20**
	Number of species				
Xanata species (38)	20	9	5	2	2
Tethya species (62)	31	17	7	4	3
Membranacea species (18)	13	5	0	0	0
Total number of species (118)	64	31	12	6	5

Table 5.3 Indicators and priority for various *Vanilla* species as reported in CIAT (2020). Indicator score between 0 (poor) and 100 (excellent) for their current conservation (CIAT, 2020).

Species	Indicator (*ex situ*)	Indicator (*in situ*)	Priority category
V. planifolia	18.6	61.1	Medium
V. pompona	9.1	41.2	Medium
V. insignis	0	53.3	Medium
V. odorata	0.2	55.6	Medium
V. appendiculata	0	51.3	Medium
V. phaeantha	2.5	46.6	High
V. helleri	0	46.3	High
V. schwackeana	0	43.9	High
V. ribeiroi	0	0	High
V. dungsii	0	0	High
V. dubia	0	31.1	High
V. fimbriata	0	25.3	High

reduce pressure on threatened *Vanilla* species include management, protection and restoration of habitats, along with advocacy and awareness-raising nationally and internationally. Furthermore, all *Vanilla* species need extensive research on threats, ecology, population dynamics, harvest and trade management (Flanagan and Mosquera-Espinosa 2016; Andriamihaja et al. 2020).

Isaac et al. (2004) concluded that, as taxonomists name more species with smaller average geographic range and population size, the assessment of species extinction rates and conservation priorities within a genus become unreliable. Karremans et al. (2020, page 491) stated:

> "Dealing with these [species] names may seem merely a taxonomic endeavor of little consequence, nevertheless significant taxonomic inflation may result in an overestimation in speciation rates, the underestimation of ecological preferences and distribution ranges, false interpretations of endemism and hotspots, skewed origin and diversification patterns, mistaken conservation priorities, and increased interest of collectors……"

For example, *V. bahiana* had been identified as a separate species due to its location in an environment where *V. phaeantha* was not found, even though they are morphologically nearly identical. Karremans et al.'s (2020) revision of the taxonomy of *V. phaeantha* recognized *V. bahiana* as a synonym, so *V. phaeantha* is not as isolated or endangered as it seems. Karremans et al. (2020) also recognized that species distribution modeling to identify areas for conservation of vanilla wild relatives, for example as reported in Watteyn et al. (2020) in Costa Rica, was impacted by taxonomic inflation on the targeting of species and localities.

Accuracy in defining species belonging to taxonomically complex groups, such as *Vanilla*, for which conventional taxonomic classification can fail, has consequences for research and conservation (Andriamihaja et al. 2020). An example of this is *V. humblotii,* which is considered endemic and protected in the Comoros, but is also found in Madagascar, so its conservation status across both localities is not clear. Both Karremans et al. (2020) and Andriamihaja et al. (2020) concluded that revising *Vanilla* taxonomy is a high priority, although the two papers suggest different approaches. Karremans et al. (2020) support the use of an integrated approach with a molecular phylogenetic study complemented by full consideration of historical records from other regions before assessing the status of conservation. Andriamihaja et al. (2020) support an integrative taxonomy approach that uses phylogenetic analysis, multiple measures of molecular-level diversity, and morphological comparisons of several individuals from different species to clarify the taxonomy.

In summary, the *Vanilla* genus includes a number of species that are at risk of genetic erosion or extinction. Among these is the most important cultivated species, *V. planifolia*. The priority gaps that require urgent attention are the Central and South American species that are not widely represented in existing *ex situ* collections. These species offer the greatest potential for improving vanilla plants' disease resistance, quality and other important traits. They also have unique aromatic properties that need to be fully explored for potential use in specialty products or fragrances. Andriamihaja et al. (2020) also identified a need to address the gaps in conservation for the leafless group of *Vanilla* species, which could prove to be important sources of drought tolerance and *Fusarium* resistance. Both classical taxonomy by experts and molecular techniques should be used to determine the inter- and intra-specific relationships to guide the priorities for collection and conservation. Systematic characterization of wild populations in terms of their adaptation and uniqueness of diversity should be used to prioritize populations and localities for conservation. Finally, concerted efforts to collect, distribute and make available the genetic material in *ex situ* collections will reduce the pressure on wild populations from overharvesting and increase the opportunities for use.

Routine operations for *ex situ* conservation

A key aspect for consideration when developing a global strategy for long-term *ex situ* conservation is the existing efficiency, effectiveness, and security of conservation by *ex situ* collection holders. Survey respondents reported that they conserve vanilla accessions as live plants in various conditions, *in vitro* as cultured plantlets, and as seed conserved at room temperature, low temperatures or cryopreserved

Table 5.4 Conservation status of *Vanilla* species.

Species	Red List category	Population trend
V. cribbiana	Critically endangered	Decreasing
V. helleri	Data deficient	Unknown
V. insignis	Endangered	Decreasing
V. planifolia	Endangered	Decreasing
V. odorata	Endangered	Decreasing
V. phaeantha	Endangered	Decreasing
V. pompona	Endangered	Decreasing
V. inodora	Endangered	Decreasing
V. somai	Endangered	Unspecified
V. hartii	Endangered	Decreasing
V. phalaenopsis	Least concern	Unknown

(Table 5.5). Live plant collections could be grown in protected shade houses with support or in botanical gardens protected in the gardens and/or conservatories. The accession could also be grown in field genebanks with support and shade from various trees. They can also be established in natural forest or restored areas alongside trees for support and shade. We did not explore all the specific difference in management for these various approach to conserve live plants. The number of accessions by conservation method is given in Table 5.5. Nine of the institutions employed more than one method of conservation. Most accessions are conserved as live plants, with only about one-fifth conserved *in vitro*. Very few accessions (1%) are conserved as seed.

The state of routine operations as carried out by survey respondents was assessed based on the general standards for field and *in vitro* collections given in Reed et al. (2004) and FAO (2014). There are no published guidelines or manuals specifically for vanilla conservation, but there are published guidelines for the safe movement of vanilla germplasm (Pearson et al. 1991). Grisoni et al. (2007) described general conservation practices for vanilla in *ex situ* collection.

Respondents reported that their shade houses or field sites ranged in area from 150 m^2 to 20,000 m^2. Most have only one site, but at least two reported planning an additional site, to mitigate risks. The FAO (2014) standards recommend at least two sites or one site and one other conservation method, such as *in vitro* culture. Only one institute reported having two sites currently; institutes using multiple conservation methods did not have all their accessions conserved using more than one method. These findings indicate that the long-term security of conservation is a concern.

The age of the plants ranged from less than one year to almost 100 years. The respondents were asked how many vines they grow for each accession. Seven respondents reported growing 1–2 plants for each accession, three respondents grow 2–10 plants and one grows 50–1300 vines for each accession, so they can meet local users' demand for planting material. The respondents concluded that the optimal number of plants per accession is 2–10, but reported that increasing the number of vines was difficult for various reasons, such as: inadequate institutional commitment and resources for establishing and maintaining plants; aging facilities; lack of appropriate space in the field, shade house or conservatory. Respondents also recognized that increasing the number of plants in a fixed site increases the risk of loss of genetic integrity from mixing accessions, especially for multiple accessions in the same species, when too many plants are grown in a small area. Other issues that constrain the number of plants or vines per accession are the shortage of vertical supports, inadequate labor for weeding and training the vines, differences in growth rate, and *Fusarium* management.

Table 5.5 Number of institutions and *Vanilla* accessions that are conserved as live plants, *in vitro* or as seed using various methods.

Methods	Number of institutions	Number of accessions
Live plant conservation		
Shade house	6	902
Botanical gardens / conservatories	9	166
Field genebank	3	296
Natural areas	4	218
***In vitro* conservation**	6	649
Seed conservation		
Seed (room temperature)	1	1
Seed (–20 °C cold room)	1	9
Seed (Cryopreservation)	1	4

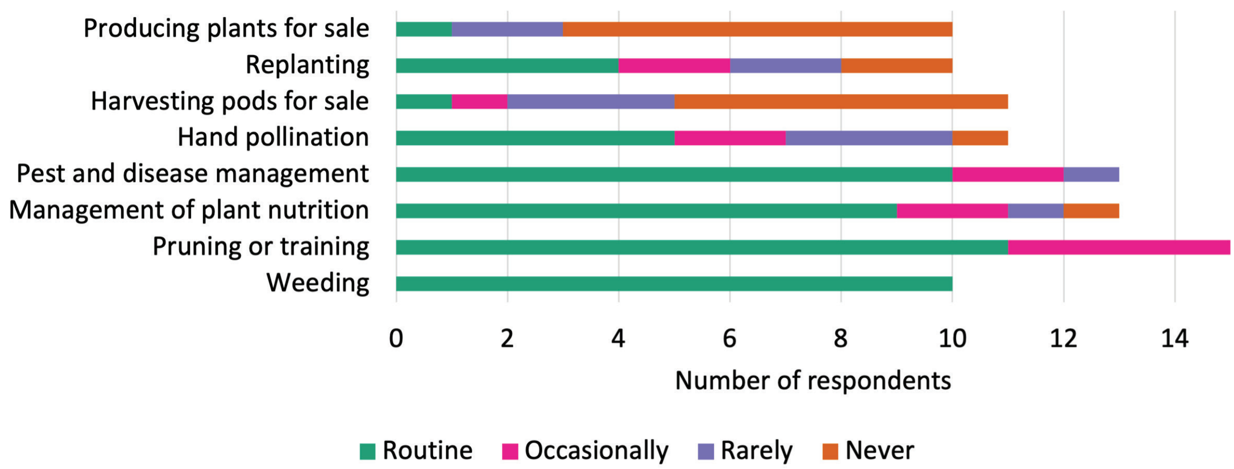


Figure 5.3 Frequency of various management activities among respondents with live plant conservation (n=15).

The respondents were asked how frequently they replanted or regenerated an accession. For vanilla conservation, replanting using stem cuttings to grow new vines, is carried out to multiply an accession, while regeneration is carried out to re-establish an accession from the original plant or population. Accessions are never strictly regenerated so whenever a new plant is collected it is given a new accession number. Three respondents reported that they have not yet needed to replant any plants, and another two stated they have done it only very infrequently, approximately every 5 years, using cuttings. Some never replant plants/vines; instead, they train the vines on trees or bamboo sticks to encourage growth. Others replant every 1–2 years to prevent losing any plants, when plants climb too far from the pot and take root elsewhere, or when plants show signs of needing a new medium or support. In these cases, respondents said they use cuttings from the existing plant if it is big enough, or from well-developed plants cultivated separately in the shade house, in either pots or in the ground.

The 15 survey respondents with live plant conservation reported having only a few routine management activities, mainly training vines to supports, management of plant health and nutrition, and weeding (Figure 5.3). As indicated earlier, replanting and hand pollination to produce pods were routine for only four of the respondents. Only one collection holder reported routinely producing cuttings for sale to growers or other users or harvesting the pods for sale.

The main reasons respondents gave for not being able to carry out conservation activities for live plants on a routine basis were: inadequate resources for facilities; high maintenance costs; inadequate specialized staff (and training) for keeping collections in ideal phytosanitary and horticultural conditions in the field, agroforestry system, or shade house. Respondents noted several other challenges too. One challenge is the need for a better system for identifying accessions. In addition, in some cases, field sites are not adequate for vanilla growth, and so achieving optimal vines will require investment to improve soil quality and natural shade. Another challenge is that staff do not have the time to carry out maintenance activities or to learn about plants' optimal growing conditions.

In vitro culture can be used not only for conservation but also for germinating immature seeds and hybrids for breeding or research. For the six respondents who use *in vitro* conservation, the main routine procedures are regular monitoring of the cultures for health and contamination, culturing, and sub-culturing (Figure 5.4). As would be expected, establishing and acclimating the cultured plant and growing-out in the field or shade house or greenhouse conditions for live plant verification of trueness to type, are carried out less frequently. The monitoring for somoclonal variation is conducted only rarely or never.

The main constraints for *in vitro* conservation as reported by respondents include a lack of specialized staff with necessary expertise and the lack of some consumables. The shortage of staff for agronomic management in field collections creates the risk that accessions will be lost before they can be established in *in vitro* cultures. Other challenges are propagating and conserving accessions *in vitro* without contamination, and transferring the small plants obtained from *in vitro* culture to shade houses for cultivation in pots. The survey results indicate that there is a need to better secure vanilla conservation by extending the use of *in vitro* conservation, by developing standard protocols and by creating more training opportunities for staff.

Some respondents reported successfully used facilities for cryopreservation for pollen for use in breeding. However, other respondents reported having very limited experience with cryopreservation for long-term conservation, and then only for seed. Hernández-Ramírez et al. (2020) reported that it was possible

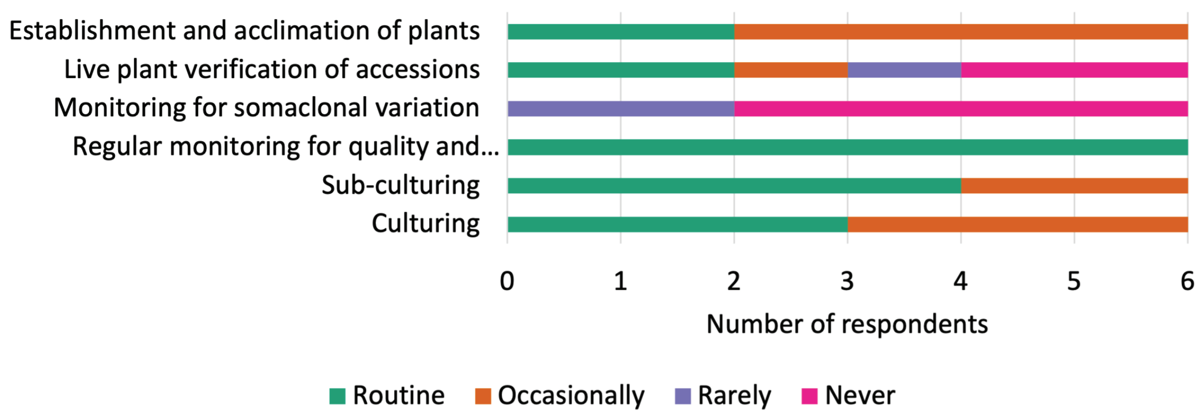


Figure 5.4 Frequency of various management activities among respondents that use *in vitro* conservation (n=6).

to cryopreserve shoot tips of *V. planifolia* for the long term, but this is an area of conservation that requires more research with a focus on developing a secure, long-term approach for *Vanilla* species. Two respondents reported that they conserve seeds, one of whom uses low temperatures and cryopreservation, but more research is needed for its wider application.

FAO (2014) standards for field collections and *in vitro* collections set out requirements for safety duplication, including the need for duplicates on more than one site within a single institute and/or the use of *in vitro* cultures, as well as duplicates stored at another institute within and/or outside the same country. However, the majority survey respondents reported that they had no safety duplication at all, or only held duplicates under the same conservation method within their own institute. Those that had safety duplication outside their own institute were more likely to use a national rather than international institute for safety duplication. No species or accessions were conserved in more than one safety duplication site, except for two respondents, who each had one species backed up in a national and an international site.

Seven respondents reported having agreed upon formal terms for safety duplication sites, and one institution has entered into a collaborative agreement for exchange, safeguarding and recuperation of donated accessions to allow for monitoring and repatriation as needed. The storage of duplicates outside the country tends to be very complicated, mainly because of policies, such as the original terms and conditions set when the accessions were collected or acquired, access and benefit-sharing terms under the Nagoya Protocol, CITES-2015 Appendix II, and national government policy. Within-country duplication also encounters difficulties, as there is limited availability of institutes with the necessary capacity and willingness. One solution under consideration by one respondent is to establish a core collection that can be shared and securely backed up to facilitate research in other locations.

No survey responses mentioned the status of duplicate *in vitro* conservation at more than one site either within or outside the country, but this is another option that would enable easier transfer of accessions. However, it would still require agreements and management.

Safety duplication is an issue for other vegetatively propagated crops also, including tea, coffee, coconut and cocoa. One possible model for vanilla might be to adopt the approach used for banana where The International Transfer Center for banana genetic resources was originally set up to address the need for clean plant material transfer of banana germplasm. However, now that the center has facilities for *in vitro* conservation and cryopreservation, it can also be used for safety duplication under terms that are consistent with "black box" safety duplication. Another option is the approach adopted for coconut genetic resources with COGENT, which is a global conservation network that involves formal collaboration between coconut-producing countries with an agreed mechanism for germplasm conservation, exchange and safety duplication. The vanilla conservation community should carefully consider adopting approaches such as these, especially given the high number of risks facing conservation and experience with loss in the past of specific accessions as well as entire collections.

The respondents were asked about the written procedures and protocols they apply in their routine conservation operations. None of the collections has written procedures, but one collection holder indicated they have a standard operating procedure (SOP) for the research assays in the lab. One respondent stated the following:

> "Although it was never the objective to have a vanilla gene bank, we have a protocol to follow in the field for sample collection tours which we apply to each plant we georeferenced. We describe the natural conditions where we collect the plant, take photos of it in its habitat and collect the previously marked plant. In the case that we send for genetic identification these plants are marked in the field. At the level of the gene bank, we do not have a manual, but we do have activities that we have been carrying out to create the management log, which will be the base to build the operating manual of the gene bank. We have a field design for the arrangement of the varieties, a map of the established accessions, state of health, growth and development, photos and we carry out activities according to what the land requires us to gradually prepare the gene bank".

From the responses, it appears that most collection holders have found themselves with a collection used for research, education, public awareness or other purposes, but not necessarily for long-term conservation. Therefore, although they have processes and procedures for managing the collection, their activities are not guided by any standard operating procedures or written protocols; rather, they are evolving as needed.

Finally, the survey asked collection holders to report on any research on conservation already underway or if they had the expertise to conduct conservation research in the future. Eight respondents identified seven possible areas for research in conservation

(Figure 5.5): to improve protocols, increase efficiency of conservation operations, increase security of conservation or address crop-specific constraints for conservation. Seven respondents were undertaking research in areas that would improve the plant growth and conservation processes or had identified these for future research. No respondent indicated they were doing research, or planned to do research, into alternative conservation approaches such as cryopreservation and seed conservation. A few of the respondents identified other areas of research, some already underway and others intended for the future, such as:

- Policies and approaches for the protection for materials *in situ* and *circa situm.*
- Metagenomics of soils and litter associated with wild vanillas belonging to the aromatic clade.
- Species distribution modeling.
- Identification of *Vanilla* species or varieties with DNA profiles.

In summary, the survey results show that the current conservation system is not secure, efficient, or rational, with all collection holders experiencing constraints and vulnerabilities. None of the survey respondents meet all the internationally recommended standards given by FAO (2014) for conservation of vegetatively propagated crops in live plant collections or *in vitro*. Collection holders lack guidelines and standards for routine conservation operations, such as SOPs, quality management systems (QMS) and research, which are necessary to ensure that the most efficient and secure procedures and protocols are being applied. Furthermore, the lack of duplication of most accessions across countries, institutes, multiple field sites or using multiple conservation methods is a key vulnerability that needs to be addressed.

Human and financial resources

For routine conservation operations to be conducted efficiently and reliably, institutes require trained staff with adequate resources, land, facilities, necessary equipment, necessary consumables for *in vitro* culture, and adequate, well-documented processes and procedures. Respondents reported that the number of staff allocated to conservation in their institute ranged from less than one to six full time staff equivalent focused on vanilla as part of the orchid collection. Staff include volunteers and students. In some cases, staff were allocated solely to managing live plant collections or *in vitro* cultures. Staff numbers, level of expertise and training were mainly deemed inadequate, especially for expanding collections or creating a dedicated vanilla genebank. Some respondents cited staff retention as a problem, especially in cases where the staff is mainly comprised of volunteers or staff pursue alternative job opportunities with greater stability. In the past, the lack or loss of dedicated staff with expertise in vanilla has resulted in the loss of collections and accessions.

Four respondents reported that their institute had an annual allocation of resources for conservation of the collection, which covered routine operations and upgrades of facilities and equipment. However, all other activities depended on project funds (known only for the few cases where respondents indicated funding sources). For most institutions and activities, funding was either stagnant or declining. Funding sources were individuals, research funding allocated for basic operations and/or specific projects, and university support.

Very few respondents indicated having recurrent funds allocated to cover the cost of conservation; any funding was deemed inadequate. Initial funds or a government allocation was provided to establish collections, but these tended not to be continued, or allocations were made each year and the amounts could not predicted. As a result, routine conservation operations depend on volunteers. Institutes occasionally allocate funding for infrastructure, but ongoing maintenance must be covered by individuals, programs or researchers from their own funding. Further-

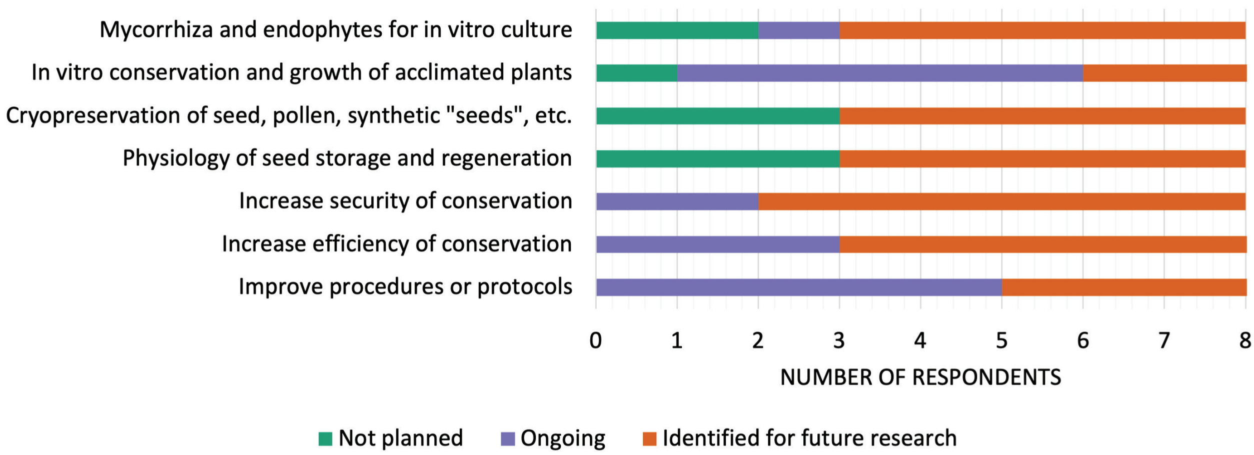


Figure 5.5 Areas of conservation research that survey respondents are currently undertaking or have identified for future research (n=8).

more, no clear donors for conservation were identified. For botanical gardens and some universities, funding to maintain accessions comes from supporters or income, which might be generated by such activities as the sale of *in vitro* seedlings, tours or farm income, or from private investors.

Respondents' overall dependence on project funds for most activities could result in insecurity and uncertainty for conservation operations, which in turn could lead to large backlogs with loss of viability of accessions or poor plant health. Dependence on shorter term project funds for activities such as propagation, characterization, evaluation, and collection indicate that there are fewer resources to invest into longer term needs such as upgrades in infrastructure and equipment, staff development, enhanced use of accessions, and securing genetic resources at risk. One solution could be lobbying governments for greater annual budget allocations for vanilla. Another approach to consider is the creation of a global competitive project fund to address urgent shortfalls in funding for routine operations, upgrades, and dealing with natural disasters.

Risk management

Risk identification and mitigation, with annual monitoring, is a key aspect of a quality management system, and is recommended in the FAO (2014) international genebank standards. However, only one respondent reported having a risk assessment that was monitored annually. The main risks identified by respondents were as follows:

- Theft of plants for national and international orchid trade.
- Natural disasters such as fire, hurricanes or other tropical storms, and drought.
- Habitat loss accelerated by expansion of agriculture.
- Loss of information about plant identity due to loss of labels or barcode tags.
- Failure of facilities during cold periods.
- Diseases, especially Cymbidium mosaic virus, *Xanthomonas*, *Fusarium* and Anthracnose.
- Pest infestations, including hairy caterpillars, leafcutter ants, scale, cockroaches, slugs and mealybug.
- Lack of space and inadequate trellising or other support for the vines to accommodate the size of the plants and the number of plants needed per accession.
- Difficulty identifying certain species that have scarce flowering and low fruit production.
- Specimens with unknown or poorly known origin and traceability.
- The challenges related to measuring, collecting, and maintaining true genetic diversity.
- Lack of national and international organizations or institutions funding the conservation of vanilla genetic resources.

Documentation

FAO (2014) international genebank standards for documentation state that "passport data of 100% of the accessions should be documented using FAO/Bioversity multi-crop passport descriptors." Therefore, the survey asked respondents about the data they held on accessions. Just under 80% of the respondents reported having information on the taxonomy, if known (Figure 5.6). More than half have photo or passport data on accessions, while one-third have phenotypic or genotypic information on the accessions. Very few of the respondents had a herbarium specimen or illustration for the specific accession. Where various types of information was available, it was not available for all accessions.

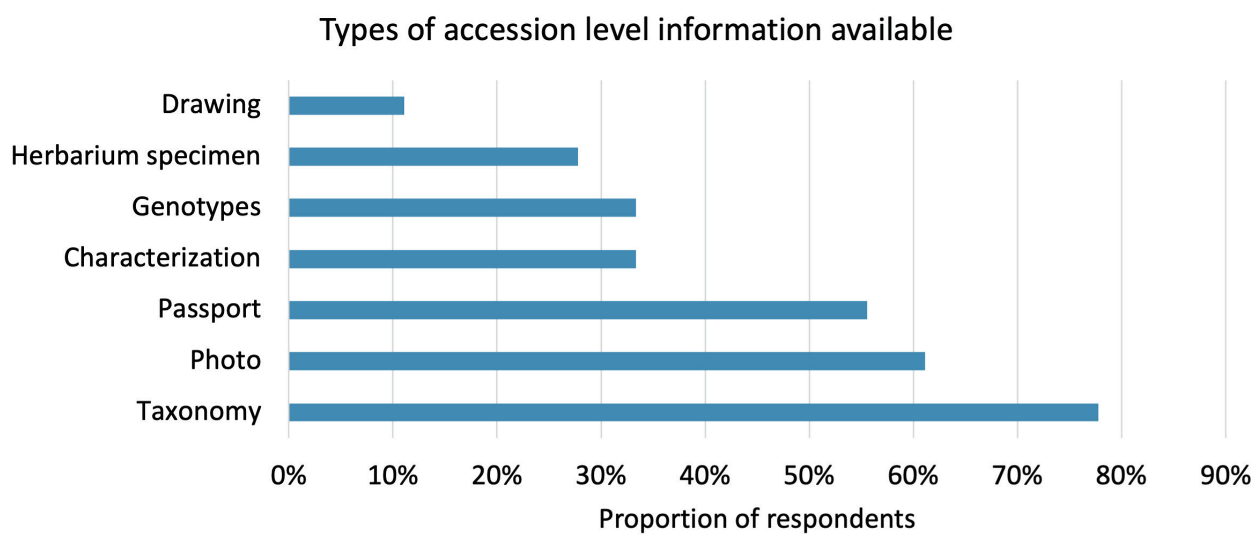


Figure 5.6 Prevalence of various types of accession-level information among respondents (n=18).

In total, 80% of respondents reported that their accession-level is available and shared only with internal staff in the institute who interact directly with the curator. A small number of the respondents reported using a searchable database available online internally and/or externally. Some of these databases had restrictions in terms of the data shared. One institution shares its accession-level information publicly in a searchable online site, such as Genesys. Overall, access to accession-level information on vanilla remains very limited for conservers and users outside each institution, which could hinder the secure conservation and use of the accessions.

In the survey, only two of the respondents reported using barcoding to some degree for the living plants and the herbarium samples.

FAO (2014) also sets out standards for storage of data generated in the genebank, both management data and data associated with the accessions, with the following recommendation: "All data and information generated in the genebank relating to all aspects of conservation and use of the material should be recorded in a suitably designed database." It was not clear if any of the respondents meet this standard. The wider adoption of genebank information systems, such as GRIN-Global or others, will not only lead to increased monitoring and efficiency of conservation management, but will also enable more online sharing of accession-level information. It will also enable better backup of documentation and greater linking of collections within the global system, ultimately enhancing the use and security of conservation.

Distribution of conserved accessions

The survey requested information on the distribution of accessions. Only 12 of the 16 institutions that responded to this survey question reported distributing their accessions. Of these, 10 have distributed to users within the institute, eight have distributed nationally and six have distributed internationally. The survey requested information on the frequency of distribution for eight user groups. For this response, respondents that had not distributed any accessions were merged with those that had not distributed any accessions in the previous five years. Generally, across all user groups, most respondents had not distributed any accessions in the previous five years or more (Figure 5.7). The user groups that most frequently received accessions were botanical gardens and academic researchers within the same country as the collection holder. Four institutions reported frequent distributions to farmers and farmer organizations each year.

The institutions that responded to the survey identified three policy issues that impacted on the distribution of accessions internationally (and sometimes nationally).

The first issue is related to CITES, which includes *Vanilla* species in Appendix II as threatened species, but allows exemptions for distribution of artificially propagated plants.

Second, vanilla is not listed in Annex I of the International Treaty on Plant Genetic Resources for Food and

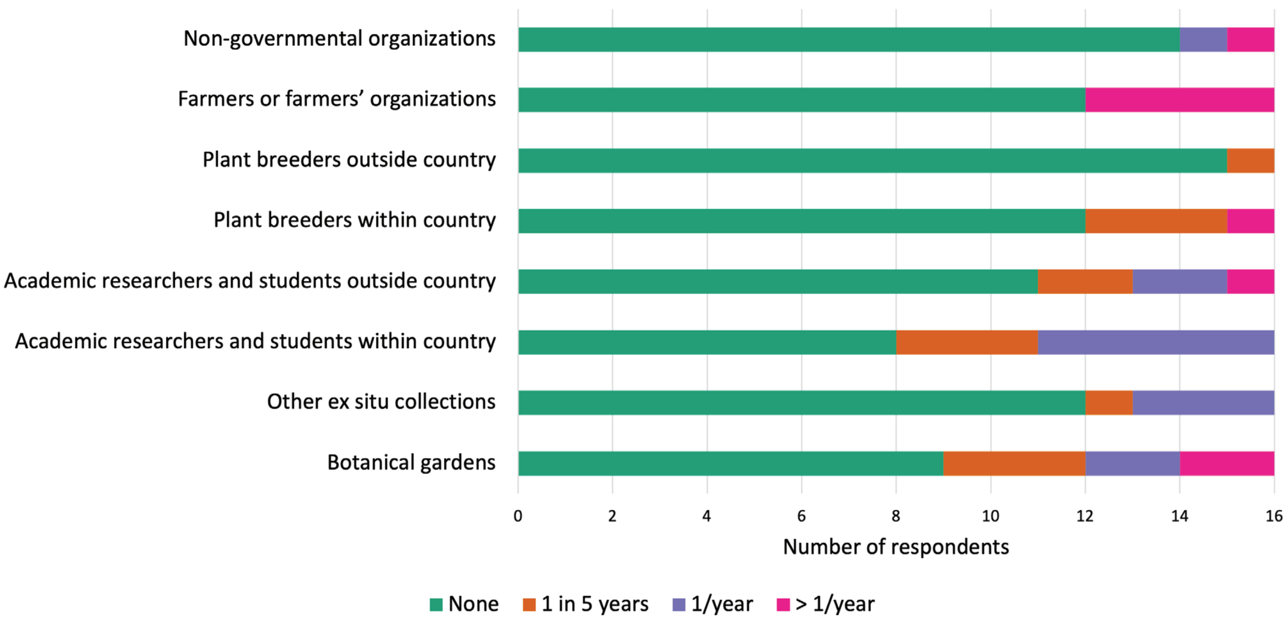


Figure 5.7 Frequency of distribution of accessions by respondents to various user groups over the previous five years (n=16).

Agriculture (ITPGRFA), which means access and benefit-sharing terms are those set by the Nagoya Protocol. David Moreno (Orquidario del Centro de Investigaciones Tropicales/Universidad Veracruzana, personal communication, 15 December 2020) described the process for exchanging vanilla germplasm from Mexico. The accession must come from an authorized collection holder, it can only be from the cultivated species, it must include a CITES export certificate that is based upon a proven providence for the current sample to be sent, and it needs a phytosanitary certificate. It might also need an agreement that complies with the Nagoya Protocal for an international exchange. No exchange is legally allowed for material collected directly from the wild, but old varieties and interspecific hybrids can be exchanged. Accessions collected from farmers can only be exchanged in Mexico and used in breeding programs in Mexico.

The third issue is the need for appropriate packaging to secure and maintain the quality of the live plant material during transportation, and the shipment through the appropriate route and process for live plant material.

The respondents were asked whether their procedures and supplies were adequate for distribution (Figure 5.8). Of the 14 respondents to this question, 64% reported having adequate procedures in place for distribution with a clear policy for exchange of accessions, an MTA or other agreement for transfer, and appropriate packaging.

Where respondents reported that their policies were inadequate, the inadequacy was related to either having no policy, having no agreement on a policy, or having no clear procedure for implementing policies. For phytosanitary certification, respondents reported that key constraints were the high cost and length of time required to get certification. With shipping, the main difficulty reported is that importers are not aware of the rules or processes for transporting and importing live plants. Other difficulties reported by respondents were related to the need for virus indexing and inadequate funding to carry out exchanges.

The respondents were asked if they imposed any restrictions on who can receive materials from their institution. Responses to this question included the following:

- National collections and native species that are endangered can only be shared with legitimate national entities.
- All exports need a Phytosanitary Certificate and Wildlife Collection Permit if collected in the wild; obtaining this permit can take a significant length of time.
- Prior permission from the country of origin is required for any distribution.
- Distribution is permitted only for non-commercial use, education, research or conservation.
- The material cannot be used for commercial purposes without the consent of the provider.
- There is no clear process for CITES-2015 certification.
- If material is used in a scientific publication, the institution must be mentioned as the source of the material.

Finally, the survey requested information on how the respondents followed up with recipients or solicited feedback on the quality and use of the accessions received. None of the respondents had any formal follow-up procedure to solicit feedback or information on use by the recipient.

In summary, distribution of vanilla germplasm by respondents tends to be concentrated within the institution or nationally. International distribution is

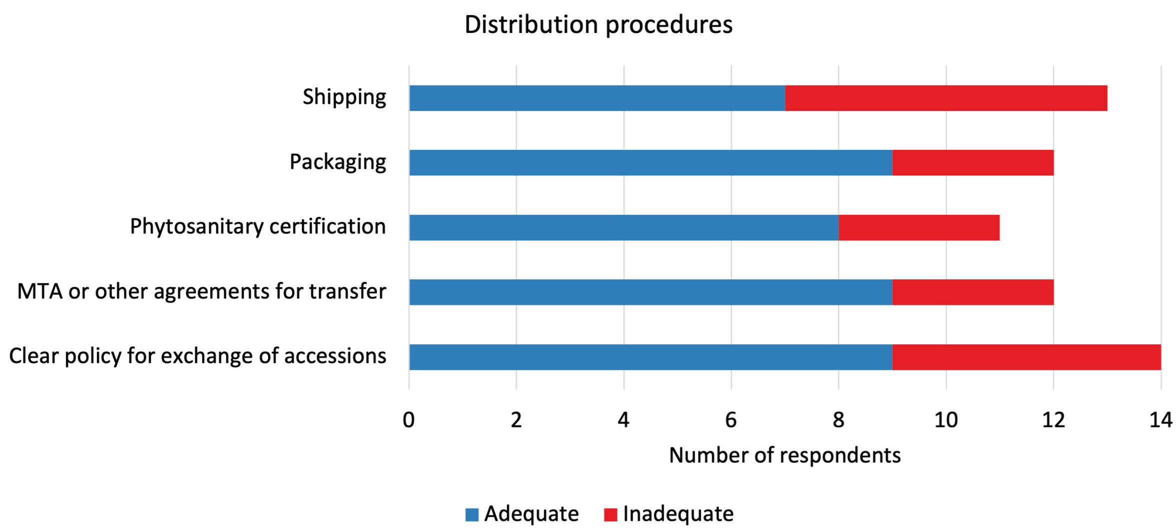


Figure 5.8 Adequacy of various procedures related to distribution, as reported by respondents (n=14).

hampered by complex policies and the high cost of distribution. Furthermore, the lack of public or private sector breeding programs for vanilla has limited the number of research users for these collections.

Links to users

Secure, effective long-term conservation and use of plant genetic resources depends on *ex situ* collection holders being connected to each other and to user groups. Therefore, the survey explored the degree and diversity of such interactions by considering collection holders' relevant partnerships and activities (Figures 5.9 and 5.10). The respondents mainly reported collaborating with other collections on research and joint collecting. More than half of the respondents had conducted activities with botanical gardens and other *ex situ* collection holders, and several had collaborated with conservers in natural sites or farmers' fields. At least six respondents had collaborated with private collectors. Only one respondent reported working with another *ex situ* collection on restoration.

Fourteen respondents reported working with university faculty and students, mainly on research and training (Figure 5.10). Similarly, research and training were the most common reasons for working with other national researchers, botanical gardens, and private collectors. A few respondents indicated that users had evaluated accessions for specific traits such as flower morphology, bean production, extract quality, chromosome number, biochemical attributes, and agronomic evaluation of the growth under various planting methods. They also genotyped the accessions mainly for phylogenetic studies and for taxonomic classification.

Seven respondents reported partnering with extension services, individual farmers or growers, farmer or grower associations and nongovernmental organizations in work that involved direct users of the accessions (Figure 5.10). This finding indicates that when a collection holder engages with local producers, either directly or indirectly, local groups benefit from the accessions conserved, and the collection holder also has greater opportunities to collect and conserve germplasm considered unique by local producers. In this way, local partnerships offer an opportunity both to secure any genetic resources that are under threat from genetic erosion or loss in the field and to contribute to local adaptation to climate change, investment in rural development, and food security.

Figure 5.9 (above) The number of respondents who reported working with other conservers on restoration, research, safety duplication, training and collection (n = 18).

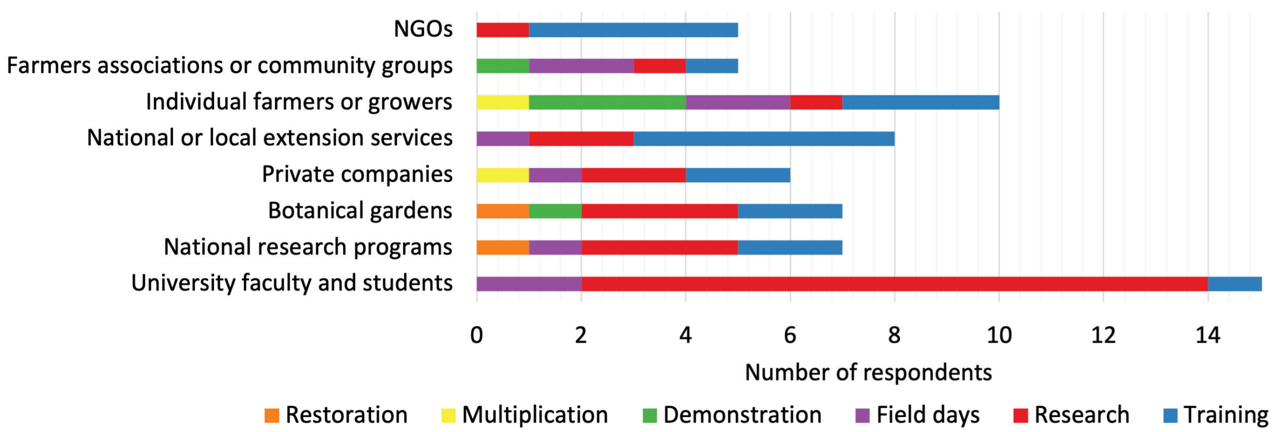


Figure 5.10 (above) Number of respondents who reported working with user groups for demonstrations, field days, research, and training (total n = 18, but 2 respondents did not answer these questions).

Although the *ex situ* collection holders surveyed are actively engaged with each other, the research community and local farmers or communities, there are very few networks or collaborative initiatives on vanilla conservation for global engagement. Vanilla researchers and germplasm collections are generally relatively well connected with other researchers from the same cultural background and language (French, Spanish, English). However, between regions, there are few interactions with regard to research projects, conferences, joint collection missions and exchange of genetic data for sequencing (e.g. Lubinsky et al. 2008a; Lubinsky et al. 2008b; Hu et al. 2019).

Some examples of collaborative networks or initiatives are:

1. There are several research initiatives between French-speaking researchers, especially in Réunion (France), Madagascar, French Guyana and French Polynesia (Dron et al. 2018).
2. There is also a strong informal Spanish-language vanilla network.
    1. Mexican Orchid Meetings have been held biannually since 2011. A community for Latin American vanilla research was founded at the Mexican orchid conference in 2014.
    2. Since then, the Latin American vanilla community has organized international congresses, held in Costa Rica in 2014 and 2016 and in Mexico in 2019. The fourth congress is planned for Colombia in 2021.
    3. Associated with the Latin American vanilla network is the Mexican Vanilla Network, an informal network that was set up with funds from the Mexican government. The network runs online seminars about vanilla genetics, germplasm and use as well as growing vanilla plants and use of vanilla products. This network thus connects vanilla researchers from across Latin America to participate in educating a wide audience.

Vanilla is gaining visibility in broader academic communities. A symposium devoted to vanilla was organized by Nicola Flanagan at the 22nd World Orchid Conference in Ecuador in 2017, which brought together a more global research community. The World Orchid Conference takes place every 3–4 years. The 23rd World Orchid Conference took place in Taiwan in 2021. The vanilla-focused meetings at the World Orchid Conference could be used to increase global engagement by strengthening connections between collection holders and researchers around the world.

Conferences more specifically dedicated to vanilla include biannual and annual symposiums on vanilla and vanillin, last held in Tanzania in 2019, and the 2009 conference on vanilla diseases, held in the USA (Exley 2010), at which the vanilla private sector and global experts came together to address specific constraints. Overall, there is a need to support and expand global efforts to connect vanilla conservers, users, industry and consumers.

Opportunities and constraints

The survey asked respondents to identify the main areas where their collection was doing well. Their responses suggest that, collectively, these conservers have strengths that could be built upon to enhance the global conservation system. Some of these positive aspects included the following:

- The collection is large and diverse and could be expanded further.
- The collection has been used for a genomics-based diversity assessment, publishing a genome, hybrid population development, and improving cultural practices.
- During collecting, locations that are rich in vanilla diversity were identified and are now being preserved.
- The field conservation sites have beneficial soil and optimal agroecological conditions for vanilla development.
- The horticultural practices in place promote growth, health, and the good development of live vanilla plants.
- The country's vanilla diversity is well represented, with herbarium vouchers conserved in fluid as a spirit collection and morphological details on accessions documented photographically.

As botanical gardens are important conservers of vanilla genetic resources, respondents were asked what specific opportunities that botanical gardens offer for securing *ex situ* collections. Respondents noted that botanical gardens have cultivation facilities, horticultural skills, and documentation protocols, as well as participation in a network of other botanical gardens and researchers. Staff at botanical gardens also have expertise in propagating challenging species, and so could prove an important resource for research. Botanical gardens serve as a platform for providing information about biodiversity to people who would not necessarily seek out this information themselves, they play an important role in raising understanding of the value of conservation and biodiversity, and hopefully, encourage people to use natural resources more responsibly. Although their involvement may be limited, botanical gardens may help to preserve some important genotypes, especially from highly threatened areas, but any work in this regard must complement the *in situ* conservation of vanilla populations. Botanical Gardens, such as Royal

Botanical Gardens of Kew, currently maintain large collections of *Vanilla* herbarium specimens and spirit collections for public use that are also conserved as live plants in some cases, which could be built upon with more global collaboration.

In the survey, respondents were given a list of aspects that are necessary to achieve secure, cost-effective, rational, and sustainable long-term conservation of their collections, and were asked to indicate whether, in their case, these were in decline, stable or improving. Although only eight of the 18 respondents provided such ratings, these responses provide some indication of the main challenges facing collection holders. For most aspects, the status was given as stable or in decline (Figure 5.11). The only area that was rated as improving by half of the respondents were increased knowledge of the genetic diversity in the collection. These findings suggest that most of these institutions are facing challenges in several areas, and require support for their conservation work, especially with regard to safety duplication, regeneration, sharing of accession-level information and expanding collections.

Some of the main challenges facing the long-term conservation and use of vanilla genetic resources globally, as identified by the survey respondents, include the following:

- Inadequate resources and management of germplasm collections, especially in countries with high native and/or endemic diversity.
- Lack of clear procedures in current process and policy for germplasm exchange across countries, which hampers international distribution.
- Increasing erosion of genetic diversity.
- Inadequate training of genebank staff
- Poor monitoring of the identity and genetic integrity of accessions.
- Incorrect identification of a large portion of vanilla plants and specimens.
- For conservers in temperate climates, there are inadequate facilities, growing space and access to germplasm.

When asked about the main advantages of having a stronger global system for vanilla conservation and exchange, survey respondents identified the following opportunities:

- To establish a more supportive environment for vanilla conservation and cultivation through collective sources of advice, expertise, programs, financial contributions, etc.
- To compile a global inventory of specimens cultivated across the world in reliable collections, to enhance access to accession-level information and to accessions for exchange.
- To enhance local use of germplasm and contribute to rural development by being able to provide resources and germplasm for breeding, direct use by farmers and market development for new products.
- To raise awareness, lobby for support and carry out other kinds of communication with the public regarding the importance of vanilla conservation.
- To support agroforestry production models for *Vanilla* species with diversified flavor and fragrance profiles for the market, which will support rural development, *in situ* protection of habitats where wild vanilla grows, and the promotion of *circa situm* germplasm banks.
- To enhance information sharing and close gaps in knowledge, taxonomic classification and species distribution modeling that may be highly relevant for long-term conservation and use.

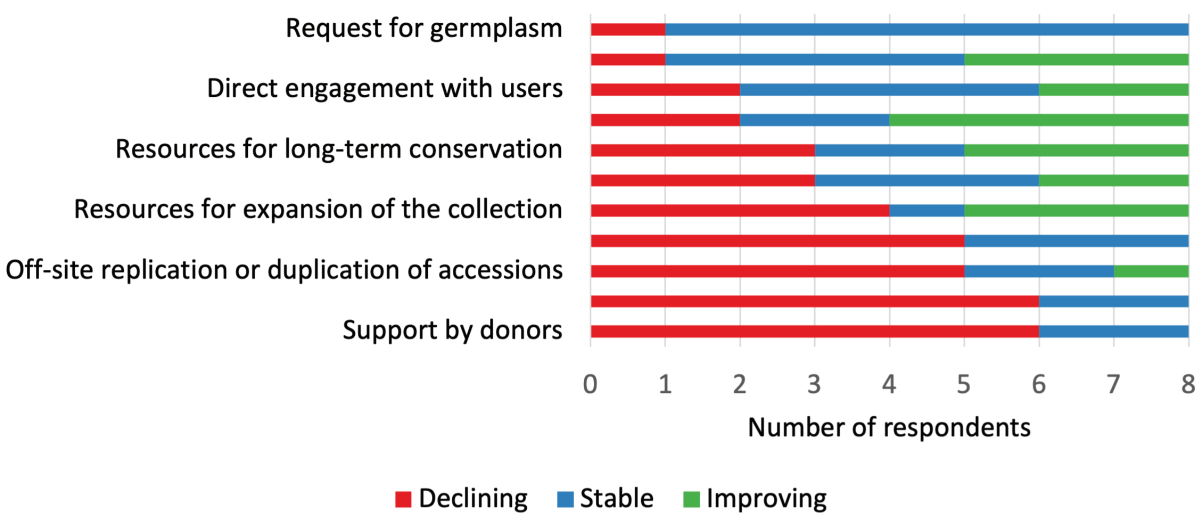


Figure 5.11 Extent to which key aspects of conservation are in decline, stable or improving, as reported by survey respondents (n = 18, but only 8 answered the questions).

Vanilla planifolia curing in Dominican Republic. Photo: A. Chambers, University of Florida

6 GLOBAL STRATEGY FOR THE *EX SITU* CONSERVATION OF VANILLA GENETIC RESOURCES

Vanilla is an important source of income for many smallholder farmers in tropical areas of the world, where vanilla production in traditional agroforestry systems or in eco-plantations is recognized to have a positive impact on biodiversity. As a high-value crop, it offers potential for livelihood improvement for these smallholders, through the development of more equitable value chains. The current global situation for vanilla production and consumption is vulnerable, however, as inefficiencies have led to an unsustainable international market system and limited national markets for the commodity.

The historical pattern of dissemination and cultivation has led to an extremely narrow genetic base for the cultivated species in the world's major production areas. This genetic uniformity poses a high risk to the future of global vanilla production and consumption. To secure production, it is essential to diversify the genetic base of the cultivars in farmers' fields, to improve disease and pest tolerance or resistance, increase tolerance to changing environments, and improve quality and yield. The diversity present in several gene pools offers potential for the improvement of *V. planifolia* and *V. x tahitensis*. Furthermore, other *Vanilla* species have unique fragrance and aroma profiles or uses in alternative medicine that have commercial value with the potential to be cultivated along with the three most cultivated species.

The genetic resources of vanilla are complex. Many existing plant populations, including those with samples in *ex situ* collections and those conserved *in situ* or *circa situm*, are highly vulnerable to land-use change, pests and diseases, variability in temperature or rainfall caused by climate change, and natural disasters. Safeguarding vanilla genetic diversity over the long term will require a concerted global effort, involving both *ex situ* conservation of accessions nationally or internationally and a combination of *in situ*, *ex situ* and *circa situm* approaches in an effective integrated strategy that considers market diversification and rural development.

The status of the global system of *ex situ* conservation of vanilla was determined based on survey responses from 18 institutions, whose combined collections account for about 62% of the estimated total number of accessions held in *ex situ* collections globally and which represent a sample of all types of institutes, albeit with a notable gap for India.

The current global system of conservation and use of vanilla genetic resources has significant redundancies for a few species and gaps in composition for key sources of genetic diversity across all species. It is not meeting international standards for conservation of vegetatively propagated crops and is generally insecure, with inefficient and poorly resourced routine operations, limited availability of plant material for users, limited sharing of accession-level information with users, and limited engagement between conservers and users globally, nationally, and locally. In summary, this is not the sustainable, rational, secure and cost-effective system that is needed for the long-term conservation and use of one of the world's most widely used spices.

In general, the background review, personal interviews, and the survey found that the conservation and use of vanilla genetic resources is of low priority for international donors, national governments, public and private researchers, local authorities, local farmers, local and urban markets, and consumers. This low priority poses a risk not only to *in situ* and *ex situ* conservation but also to the continued conservation of diversity *circa situm* in farmers' traditional agroforestry production systems.

The current global system for the conservation and use of vanilla genetic resources consists of the following elements:

- Local farmers and households in centers of diversity who conserve and manage most of the diversity of cultivated species (*V. planifolia* and *V. x tahitensis*).
- Natural areas that contain most of the diversity of wild relatives, but that are not subject to conservation monitoring.
- One globally known collection, BRC Vatel in Réunion, whose large collection contains a diversity of species.
- Four or five key national collection holders in Central and South America that conserve mainly unique local vanilla diversity with very limited and unreliable national support, but with opportunities for local engagement with users.
- Other collections at universities or botanical gardens that are located outside the center of diversity and mainly conserve accessions that are duplicates or replicates of those held by others; however, their support comes from private and/or national sources, so, given changing priorities, their future contribution to vanilla conservation and use is uncertain.
- Smallholder farmers, mainly in Madagascar, Indonesia, Uganda, Tahiti, and Papua New Guinea, who are the main producers of vanilla globally, with limited genetic diversity in their fields and very limited investment in variety improvement nationally.
- Private industry, which depends on the availability and quality of processed vanilla products from real vanilla for flavoring in food, fragrance, and other uses, but which also has an interest in new sources from a diversity of *Vanilla* species.

The current global *ex situ* conservation system does have some advantages that can be built upon to enhance long-term conservation and use. The survey respondents identified three *ex situ* collections that other conservers can turn to for expertise and guidance:

1. BRC Vatel in Réunion
2. CITRO in Mexico
3. INSEFOR in Costa Rica

The University of Florida is also recognized as an important *ex situ* collection holder, given its experience in conservation and in application of genomics. These four genebanks could serve as key conservers and lead conveners in any global effort to increase security of *ex situ* conservation, adopt new technologies and methods, enhance capacity and expertise on the conservation and use of vanilla genetic resources, and collectively address some of the major constraints in the shift to a more sustainable global system.

These genebanks and key botanical gardens, many of who participated in the survey (Annex III), could assume a leadership role in advocacy and communications on the importance of conservation and use of vanilla crop diversity at a national or local level.

Other advantages in the current system are related to the national and local nature of conservation, in that value-added research and development can directly utilize local germplasm with the involvement of local farmers and consumers. A number of other institutions and private individuals have local collections, links to farmers who conserve diverse genetic resources through their own use, and links to *Vanilla* species being conserved *in situ*. The future global system needs to strengthen the links between the four key collections and these other nationally based conservers. Connections can be strengthened through greater collaboration in areas such as research, capacity building, germplasm exchange and securing conservation.

The main disadvantages of the current system are: the lack of committed annual support for conservation of vanilla in these nationally or privately held collections; the general lack of knowledge on the diversity that is conserved; the low level of support for research in vanilla; and the vulnerability of much of the diversity to loss, whether in live plant collections, farmers' fields or natural areas.

Therefore, an important task for the future global system is to raise awareness of the need for greater long-term support for the conservation and use of vanilla genetic resources. It is also necessary to facilitate investment in research, not only into vanilla crop improvement, in order to address challenges related to disease and climate change, but also into the use of diverse *Vanilla* species and interspecific hybrids for developing further specialty markets for new vanilla flavorings, fragrances or medicinal uses, through greater collaboration with the private sector.

The purpose of this strategy is to recommend priority actions to shift to a global system of conservation and use that is more secure, rational and cost-effective, with greater engagement with users. These recommended actions will be used by the Crop Trust and others to identify key investments and generate the support needed to secure the long-term conservation and use of vanilla genetic resources.

Vanilla bean storage. Photo: Sunil Elias/Wikimedia

7 RECOMMENDED PRIORITY ACTIONS

A global strategy must identify the key priority actions, who should be involved, and the resources required. Consultation with stakeholders is a necessary step, but to facilitate the discussion, three strategic areas have been identified based on the survey results, along with key actions, as follows.

1. **Secure the long-term conservation of vanilla genetic resources:**
   a. Address insecurity in current *ex situ* conservation caused by suboptimal routine operations, facilities, safety duplication and conservation research.
   b. Address the risks of losing the unique diversity conserved *circa situm* in farmers' fields and *in situ* in natural areas.
   c. Address constraints to global engagement of conservers and users.
   d. Increase advocacy and communications on the importance of vanilla and its conservation.
2. **Increase the availability and exchange of germplasm:**
   a. Address constraints to distribution through improved plant health and better growth conditions for propagation.
   b. Facilitate distribution through transparent management of policy bottlenecks.
   c. Address constraints to distribution caused by phytosanitary issues.
3. **Increase the use of the genetic diversity conserved:**
   a. Increase access to accession-level information, preferably making it available online to all potential users.
   b. Increase evaluation and genotyping, with results openly shared with users.
   c. Establish a core collection or other subsets, and make them available to others, in order to facilitate use.
   d. Support ongoing engagement of collection holders with researchers and farmers.
   e. Ensure implementation of access and benefit-sharing protocols for germplasm exchange.

Taking the key actions in these three strategic areas will contribute to the creation of a sustainable, rational global system for long-term conservation and use. However, a major obstacle preventing individuals in the global system from taking these actions is that there are insufficient opportunities for global collaboration that builds upon institutional and individual expertise and commitment to secure vanilla genetic resources. Building this collaboration will require dedicated global funds allocated to the specific actions. To take the key actions required in the three strategic areas there will be a need for committed global leadership to advocate for the allocation of dedicated global financial resources to implement these actions, both from increased annual allocation as well as more targeted specific funds.

In summary, drawing on the survey findings and background review, three priority actions have been identified as the initial steps for the strategy.

Priority Action 1

Hold a global workshop on the conservation of vanilla genetic resources, to inform stakeholders of the status of conservation and establish a platform for global collaboration

It is necessary to build an effective platform for networking and communications, so that conservers of vanilla genetic resources can collaborate and connect with key users and other stakeholders. An effective means of communication will enable those involved in *ex situ* conservation to:

- share experiences.
- collectively improve conservation practices.
- establish quality management systems, protocols, processes, and standards.
- help build each other's capacity.
- address the need for safety duplication
- adopt genebank information systems and share accession-level information.

Furthermore, collection holders could use the platform to raise awareness to address the declining support for specific collections or localities where vanilla genetic resources are at risk of loss due to natural disasters, reductions in local production, loss of resources, loss of expertise and other causes that might require an urgent response. The platform could also serve as a source of experts when needed, for example, when seeking to close key gaps in diversity through collecting or re-collecting.

This platform could mainly be run virtually, with in-person meetings when funds are available. It could be an expansion of the informal working group that now operates in Central and South America. Although the network would not have a formal structure or leadership, it would require institutional commitment for facilitation.

Although an ongoing networking platform is desirable, a formal workshop is also needed. Existing international and national orchid conferences that are held annually or biannually could be used as an opportunity to raise awareness of the status of global conservation of vanilla genetic resources. Other organizations within the vanilla industry, such as the Sustainable Vanilla Initiative, could also convene global discussions among the various private and public sector institutions involved in conservation and use. In addition, stronger links are needed between those involved in vanilla research and those involved in the conservation and use of vanilla genetic resources, to build capacity for addressing the urgent needs for securing vanilla genetic resources over the long term.

Workshops on vanilla genetic resources also offer opportunities to bring together conservers, users and the vanilla industry. An initial workshop on Vanilla Genetic Resource Conservation and Use would have three main objectives:

- Raise awareness and advocate for actions for better conservation and use of vanilla genetic resources, for the future sustainability of the vanilla sector.
- Establish a platform for global collaboration.
- Establish working groups within the platform for collective action on priority needs.

Priority Action 2

Establish a global fund to support the long-term conservation of unique vanilla diversity

Financial support for long-term conservation and use of vanilla genetic resources is not a priority for many donors, which means institutes have little in the way of annual or project funding to address vulnerabilities. A number of priority needs have been identified in terms of routine operations, facilities, equipment and research on conservation, as genebanks tend to rely on short-term targeted project funds, which are not predictable, and seem to be declining. The lack of global action to address these collection-specific constraints poses a risk to the conservation of a high proportion of the unique diversity of vanilla. If a global fund is established, with a competitive grants scheme, institutes would have the means to carry out priority actions. The fund could be set up to require complementary funds from national governments or individual institutions for a specific project, as well as a commitment to increased annual budget allocations to secure the long-term conservation of this key global resource, which also has significant value for individual nations.

Survey respondents identified several high-priority actions, which should be considered for funding through the global fund, as follows.

- Establish a mechanism to facilitate the exchange of seed/pollen/plants between collection holders and

users, within existing constraints under policy and phytosanitary requirements.
- Establish best practices, guidelines and standard procedures for the secure, long-term conservation of accessions.
- Establish an approach to safety duplication in order to secure genetic resources at a number of sites and/or via a combination of conservation methods, and hence minimize the risk of loss. The approach should include opportunities to utilize facilities that already have the right climatic conditions, propagation facilities, horticultural skills, documentation protocols and good prospects for long-term commitment. It should consider operational models currently used by other crop communities (e.g. banana, cocoa, coconut) for global conservation, safety backups and germplasm exchange.
- Employ genomic tools to assess current interspecific and intraspecific genetic diversity in *ex situ* collections and in populations under natural conditions, in order to facilitate rational decisions on what to conserve, how to conserve it and what resources are needed for long-term conservation.
- Establish an international core collection for vanilla that can be shared for research and breeding.
- Enable accession-level information sharing on a global platform such as Genesys.
- Undertake the characterization of genetic resources through globally agreed standard descriptions for morphological, molecular and biochemical descriptors or chemotype profiles.
- Produce a revised, curated list of *Vanilla* species, with a solid phylogenetic framework and a set of reference markers that can be used to facilitate taxonomic classification and species distribution modeling for determining conservation priorities.
- For the long term, undertake research and develop protocols to conserve seed collections for high-priority species and populations under optimal conditions to maximize their longevity.
- Facilitate national/international breeding programs to utilize conserved genetic resources for the improvement of disease resistance, flavor and fragrance compounds, and biotic stress tolerance and other adaptations to climate change.
- Expand the evaluation and use of vanilla genetic resources by researchers, growers and processors to diversify production and market systems, sustain agroforestry systems and enhance rural development.

If most of the major collection holders become involved in these activities, the entire community will benefit from the opportunities to share resources, experience, and expertise globally. The network should play a major role in setting priorities and targets for projects, collaborating on projects, monitoring projects and communicating results.

Priority Action 3

Establish a global initiative to secure the *ex situ, in situ* and *circa situm* conservation of unique vanilla diversity

There is a need for a systematic survey and inventory of inter- and intra-species diversity of the vanilla in *ex situ* collections, farmers' fields, and natural areas, from which a global map of the distribution of *Vanilla* species can be constructed. Also recommended is a global conservation planning exercise, to determine key priority sites to be targeted for detailed *circa situm* and *in situ* conservation interventions, including the creation of genetic reserves for vanilla genetic resources. The conservation interventions should include an early warning monitoring system for tracking the risk of loss of vanilla genetic diversity from farmers' fields and natural areas.

Furthermore, *ex situ* collections require stronger links and collaboration with *circa situm*, *in situ* and other protected sites, to secure the global diversity of cultivated and wild species in section *Xanata* and key representatives of section *Tethya*. This can be achieved by better linking global and national initiatives so that *ex situ* collection holders can offer their expertise and support to local farmers and those managing natural areas, mainly in Central and South America.

Increased engagement with farmers, farmer associations, community groups, NGOs and national extension services is also an important priority for the global system, given the limited research into crop improvement and the low number of providers of planting material in the private sector. Increased engagement will facilitate local access to these key genetic resources and ensure greater conservation through collection and safety duplication.

All these activities will require investment in developing and establishing a global initiative aimed at:
- securing vanilla diversity in farmers' fields and *in situ* in the most important centers of diversity.
- collecting and conserving samples of this diversity in key *ex situ* collections.
- collaborating with national and local authorities to ensure their long-term commitment to conservation.

This global initiative could be funded by the global fund detailed in Priority Action 2, or by additional funds, but it must build upon past efforts and strategic planning to ensure its sustainability.

University of Florida vanilla collection. Photo: A. Chambers, University of Florida

8 NEXT STEPS

The next step in implementing this global strategy will be the establishment of a global coordination committee with the initial participation of some of the key institutions and individuals who contributed to the strategy development. This coordinating committee would plan and facilitate consultations with stakeholders on the global strategy and the implementation of the proposed priority actions. This could be one consultation or a series of consultations that would need to be decided by this global coordination committee. An initial virtual consultation should be held with the key players in the vanilla sector, to raise their awareness and seek their support of the actions needed to secure vanilla genetic resources. This could be convened by the Sustainable Vanilla Initiative with its industry members, as this would engage the conservation and use community as well as key national governments.

In addition, a consultation with representatives from the vanilla research and conservation community will focus on building consensus on the top priority actions, develop an implementation plan with estimated costs, and identify who will be involved. These virtual consultations will inform plans for the global conference or workshop identified in Priority Action 1. These consultations could be facilitated by the Crop Trust and could initially be held regionally to deal with differences in time zones and languages. The Central and South America consultation could utilize the existing Facebook group and could be led by CITRO, given its expertise and wide experience in vanilla genetic resources, and/or held within the framework of the IV International Vanilla Conference at the Pontificia Universidad Javeriana in Cali, Colombia. The Asia and Africa regional group could be led by BRC Vatel in Réunion and include participants from collection holders in those regions, as well as Royal Botanic Gardens, Kew, which has relevant partners in the region. Participants should include the 18 genebanks that participated in the strategy development, as well as the important collections that did not respond to the survey, namely IISR in India and Vanille de Tahiti. It could also include key national policy experts for CITES and Nagoya access and benefit sharing (ABS); key user groups, such as researchers from universities, national research programs, NGOs, Botanical Garden Conservation International (BGCI); and key private sector companies with representative of the national and international spice associations that have a vested interest in the sustainability of the crop. In total, at least 45 participants would be expected to take part in the virtual consultation, with a total estimated cost of US$15,000 to support facilitation, translation, and additional support for participants as needed.

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10 ANNEXES

Annex I. Selected metrics for vanilla and ginger (as comparison)

This appendix was written by Dr. Felix Frey, International Consultant, Global Crop Diversity Trust

Khoury et al. (2021) compiled a comprehensive dataset as part of a project funded by the International Treaty on Plant Genetic Resources for Food and Agriculture and the Crop Trust, led by the International Center for Tropical Agriculture (CIAT). The aim was to introduce five normalized reproducible indicators to serve as an evidence base for use when prioritizing actions on the conservation and use of plant genetic resources for food and agriculture. The indicators encompass metrics associated with the USE of a crop (Global importance), the INTERDEPENDENCE between countries with respect to genetic resources, the DEMAND among researchers for genetic resources, the SUPPLY of germplasm by genebanks and the SECURITY of germplasm conservation. Graphs of the indicator results are publicly available on an interactive website. To generate the five indicators, Khoury et al. (2021) collected a comprehensive dataset from multiple sources. We do not present those indicators here, but rather discuss the underlying raw data to shed light on the aspects represented by the indicators.

To put some numbers into context, we compare vanilla with ginger. These two crops are comparable with respect to type of propagation and use (both are spices). *Vanilla* and *Zingiber* are the genera of vanilla and ginger, respectively. To represent the main species used in vanilla production, Khoury et al. (2021) used *V. planifolia*, *V. pompona* and *V. x tahitensis*; ginger is represented only by the species *Zingiber officinale*.

The metrics for "Global production," "Food supply" and "Quantity exported globally" under the indicator domain "Crop use" are annual average values drawn from FAOSTAT for the years 2010–2014 (Khoury et al., 2021). The percentage of countries producing and consuming (being supplied with) the crop is calculated as the number of countries, where the respective crop is within the top 95% of most important crops divided by the number of countries that report respective numbers (can be different between metrics and crops). Global production of vanilla totals about 8,000 tons annually, which is 0.4% of global ginger production (2.3 M t). The food supply of vanilla (i.e. average global consumption) is about 0.8 mg/cap/day; by comparison, ginger supply is 222 mg/cap/day. The food supply of ginger and vanilla are not directly reported by FAOSTAT; instead, they are included with other spice crops in the category "spices, others." Khoury et al. (2021) inferred the food supply of ginger and vanilla from the total food supply of "spices, other" (2 g), taking into account total global production shares of the spices in that category.

Vanilla production is restricted to a very few equatorial regions of the world; only 7% of countries produce vanilla, whereas 19% of countries produce ginger. Both ginger and vanilla are internationally important spices, which is why a huge share of production is exported. In total, 25% of ginger (564,405 t) and 61% (4,941 t) of vanilla produced are exported. The main importing countries of vanilla are located in Europe and North America. However, 39% of vanilla is apparently consumed or processed locally. This is because three of the five top producers of vanilla are also among the five top consumers of vanilla (Indonesia, Papua New Guinea and Mexico).

The crop use metrics with respect to research were assessed using a manual search on Google Scholar, searching for the respective genus or species in the titles of publications, including patents and citations, between the years 2009 and 2019 (Khoury et al., 2021). Search hits on Google Scholar indicate the level of scientific interest in a crop. The *Vanilla* genus was found in 1,470 publication titles, which is one third of of publications which include *Zingiber* (ginger) in their title (4,490 publications). The most important vanilla species, *V. planifolia*, *V. pompona* and *V. x tahitensis*, were mentioned in 417 publications (28% of the publications found to mention *Vanilla*). We therefore assume that most of the articles on *Vanilla* cover multiple species, including wild species, and multiple uses of vanilla (as the genus and common name are the same), where the individual species are not of major interest. By contrast, for ginger, most (77%) publications that mention "Zingiber" also include the species name *Zingiber officinale*.

Khoury et al. (2021) defined interdependence as a measure for the degree of dependence of the global cultivation and use of a certain crop from germplasm present at the primary centers of diversity of the respective crop. Primary centers of diversity are not represented by countries, but by 23 agroecological zones (Khoury et al. 2016), as crop diversity does not follow national borders but rather climatic and agroecological boundaries. Interdependence is high in crops that originate from a small area and are cultivated and used globally. For production, interdependence is calculated by dividing a crop's production outside the primary center of diversity by the global production. If all production is outside the primary center of diversity, interdependence would be 100%. For food supply, interdependence is calculated by dividing the food supply by the world average. Food supply outside can be higher than that inside the primary centers of diversity and thus also higher than the global mean. Therefore, interdependence with respect to food supply can be above 100%. Vanilla interdependence for production is very high at 96%; by contrast, production interdependence for ginger is 65%. This is because the main production areas of vanilla are in the Indian Ocean region and Southeast Asia and thus outside the primary centers of diversity (Central and tropical South America). Interdependence of food supply of vanilla per capita is very high (104%), which indicates that food supply is higher outside of the primary centers of diversity. This reflects the fact that, among the five main consumers of vanilla products (United States, Indonesia, Papua New Guinea, Mexico and France), only one country is located in the primary center of diversity of vanilla (Mexico). In contrast, for ginger, interdependence with respect to both production and food supply are relatively low, as a large share of production and consumption takes place in the primary center of diversity (South Asia).

Demand for germplasm is defined by two metrics: (1) the number of distributions of accessions by genebanks, as an annual average between 2014 and 2017 drawn from the Plant Treaty Information System; (2) the number of varieties released during the five years between 2014 and 2018, obtained from the International Union for the Protection of New Varieties of Plants (UPOV). Only two vanilla accessions were distributed by genebanks per year between 2014 and 2017, which is a very low number, but in the same range as the annual distributions of ginger germplasm (8). The exchange of vanilla germplasm is highly limited for a couple of reasons. First, in most cases legal exchange procedures for vanilla germplasm between countries are not yet established, second, most genebanks do not have sufficient funding to, characterize and maintain their vanilla collections sufficiently in order to be able to exchange material efficiently. Third, communication and information exchange are hampered by language and cultural barriers between vanilla communities across the world, and forth, to date, by the absence of a global strategy for the conservation and use of vanilla genetic resources. In the five years from 2014 to 2018, two new vanilla varieties were released, which reflects the early efforts to address the very low genetic diversity in cultivated vanilla (due to vegetative propagation) and threats by biotic and abiotic stresses, such as *Fusarium* infections and drought. This is only 11% of the number of ginger varieties released in the same period (19). Given the global importance of vanilla, efforts to breed new varieties should be intensified.

Khoury et al. (2021) illustrated the supply of germplasm by using the number of accessions available in *ex situ* collections around the world, with respect to the crop genus and the most important species of the respective crop. They also assessed the number of accessions (again with respect to genus and species) available under the multilateral system (MLS) of the Plant Treaty. This assessment was done first, directly, as notation (in MLS / not in MLS) in the public online databases Genesys, FAO WIEWS and GBIF. Secondly, the availability of accessions was assessed by considering whether the country hosting the institution that held the respective germplasm collection was a signatory to the Plant Treaty, in which case, the accession was regarded as available via the MLS. According to the databases, global *ex situ* collections hold a total of 309 *Vanilla* accessions.

According to official statistics, therefore, global vanilla collections are about 1.5 times the size of international ginger collections (210 *Zingiber* accessions), even though ginger has greater global importance (production, food supply, trade). However, the numbers for vanilla global collections are considerably underestimated. Most collections do not report their numbers to databases, and our survey found that numbers of *Vanilla* accessions stored in *ex situ* collections are much higher in reality (~1,800). The numbers of accessions reported for the three main *Vanilla* species *Vanilla planifolia*, *Vanilla pompona* and *Vanilla tahitensis* (179) are also highly underestimated. Our survey found that about 1,000 accessions account for the species in the primary vanilla gene pool, *V. planifolia* and *V. x tahitensis*, which does not include *V. pompona*. Neither vanilla nor ginger are listed in Annex I of the Plant Treaty. Therefore, no accessions are available under the MLS. Accessions of vanilla can be exchanged under bilateral agreements, but our survey revealed that the bulk of vanilla collection holders do not have adequate procedures in place for effective exchange of accessions, given requirements related to policy, packing, phytosanitary certification and shipping.

Security of germplasm conservation is represented here by two metrics: safety duplication at the Svalbard Global Seed Vault (SGSV) and the equality of global distribution with respect to several crop use metrics. The numbers of accessions, by genus and species, safety duplicated were taken from the SGSV website and divided by the total number of accessions stored in global *ex situ* collections (see above), with the result giving the percentage of germplasm that is safety duplicated. To represent the equality of distribution across different agroecological regions of the world (Khoury et al. 2016), Khoury et al. (2021) used the reciprocal 1-Gini index with respect to the crop use metrics. The Gini index is the most commonly used inequality index (Gini Index 2008), known foremost for the quantification of global income inequality. The 1-Gini index, presented here, ranges from 0 to 1, where 0 reflects very unequal distribution across world regions and 1 reflects a completely equal global distribution across regions. It reflects the security of crop cultivation and use, where, for example, small indices of production and thus geographic restriction go hand in hand with a higher vulnerability of supply, as in the

Table 1 (of Annex I). Selected metrics collected by Khoury et al. 2021 for vanilla and ginger, subdivided by indicator domain.

Metric	Vanilla	Ginger	Vanilla/ Ginger
Crop use			
Global production [tons]	8,154	2,247,322	0.4%
Food supply (Amount consumed) [g/capita/day]	0.0008	0.2220	0%
Percentage of countries producing crop *	7%	19%	40%
Percentage of countries consuming (being supplied with) crop *	95%	95%	100%
Quantity exported globally [t]	4,941	564,405	1%
Number of publications between 2009–2019, including patents and citations, searching title of publication (Google scholar search hits) for genus **	1,470	4,490	33%
Number of publications between 2009–2019, including patents and citations, searching title of publication (Google scholar search hits) for species ***	417	3,440	12%
Interdependence			
Interdependence of global production from germplasm from primary centers of diversity [0-1] ****	96%	65%	148%
Interdependence of global food supply from germplasm from primary centers of diversity [0-1] ****	104%	59%	177%
Demand			
Accessions distributed from genebanks (Annual average 2014–2017)	2	8	26%
Variety releases in 5 years (2014–2018)	2	19	11%
Supply			
Number of accessions in *ex situ* collections of genus **	309	210	147%
Number of accessions in *ex situ* collections of species ***	179	141	127%
Accessions of the genus ** available through Multilateral System (MLS) directly noted in databases [%]	0%	0%	
Accessions of the species *** available through Multilateral System (MLS) directly noted in databases [%]	0%	0%	
Accessions of the genus ** available through Multilateral System (MLS) indirectly by matching institute countries with party status [%]	0%	0%	
Accessions of the species *** available through Multilateral System (MLS) indirectly by matching institute countries with party status [%]	0%	0%	
Security			
Accessions of genus ** safety duplicated in Svalbard Global Seed Vault [%]	0%	0%	
Accessions of species *** safety duplicated in Svalbard Global Seed Vault [%]	0%	0%	
1-GINI index for equality of production across the world [0-1] *****	0.011	0.017	66%
1-GINI index for equality of food supply across the world [0-1] *****	0.158	0.158	100%

* Counting countries which list the crop as within top 95% (FAOSTAT); Calculated as: Number of countries counting crop (top 95%) / Total number of countries (production 216, food supply 175)

** Vanilla: Vanilla, Ginger: Zingiber

*** Vanilla: *Vanilla planifolia, Vanilla pompona, Vanilla tahitensis* (or *x tahitensis*); Ginger: Zingiber officinale

**** Global metric / Metric at primary center of diversity

***** Relative equality of crop use across world regions (same regions as used in interdependence domain), high equality give high indicator value case of natural disasters. None of the reported vanilla (nor ginger) accessions are safety duplicated at SGSV. Vanilla plants rarely produce seeds and are propagated clonally (like ginger). Nevertheless, vanilla seeds could be used to store vanilla diversity over the long term, although certain cultivars show segregation of their progeny and thus, can only be conserved vegetatively. Efforts are underway to cryoconserve vanilla germplasm *in vitro* (Cruz-Cruz et al. 2013; Hernández-Ramírez et al. 2020), which is a very promising approach for long-term conservation and duplication at SGSV. Research in this field should be intensified. The equality of distribution with respect to global production of vanilla is very low, at 0.011, and lower than the equality of distribution of ginger (0.017). This is obviously due to the more restricted area of production, as stated above, with 90% of vanilla produced in Madagascar and Indonesia. Vanilla supply is thus highly vulnerable to regional shortfalls of production, due to, for example, natural disasters or local pathogen outbreaks. The equality of distribution of food supply across different regions of the world for vanilla is relatively high at 0.16 (same number as ginger), compared to the equality of distribution of global production. The higher equality of distribution of food supply of vanilla reflects the wide use of vanilla (and spices in general) in a wide range of food products.

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Annex II. Number of accessions of *Vanilla* species conserved in *ex situ* collections

Number of accessions of *Vanilla* species conserved in *ex situ* collections, and number of conserving institutions, with taxonomic section and region of origin.

***Vanilla* species**	**Globally[1]**		**In survey**		**Section**	**Region of origin**
	No. of institutions	**No. accessions**	**No. of institutions**	**No. accessions**		
Vanilla planifolia Andrews	181	1092	15	697	Xanata	Central/South America
Vanilla x tahitensis J.M. Moore	19	23	2	2	Xanata	Central/South America
Vanilla pompona Schiede	84	235	15	139	Xanata	Central/South America
Vanilla odorata C.Presl	8	88	6	55	Xanata	Central/South America
Vanilla insignis Ames	13	55	7	33	Xanata	Central/South America
Vanilla phaeantha Rchb.f.	7	47	6	39	Xanata	Central/South America
Vanilla hartii Rolfe	7	12	4	8	Xanata	Central/South America
Vanilla dressleri Soto	1	11	1	11	Xanata	Central/South America
Vanilla palmarum Salzm.	10	11	4	6	Xanata	South America
Vanilla chamissonis Klotzsch	7	7	4	4	Xanata	South America
Vanilla karen-christianae Karremans	3	6	2	5	Xanata	Central/South America
Vanilla trigonocarpa Hoehne	3	5	2	2	Xanata	Central/South America
Vanilla appendiculata Rolfe	4	4	2	2	Xanata	South America

Vanilla species	Globally[1]		In survey		Section	Region of origin
Vanilla carinata Rolfe	4	4	0	0	Xanata	South America
Vanilla cribbiana Soto	3	5	3	5	Xanata	Central/South America
Vanilla bicolor Lindl.	3	3	1	1	Xanata	Central/South America
Vanilla helleri A.D.Hawkes	2	2	1	1	Xanata	Central/South America
Vanilla cobanensis Archilla	2	4	1	3	Xanata	Central/South America
Vanilla imperialis Kraenzl.	39	45	5	10	Tethya	Africa
Vanilla madagascariensis Rolfe	28	39	8	16	Tethya	Africa
Vanilla aphylla Blume	33	38	6	8	Tethya	Asia
Vanilla barbellata Rchb.f.	13	26	3	13	Tethya	Central/South America
Vanilla roscheri Rchb.f.	17	24	5	9	Tethya	Africa
Vanilla dilloniana Correll	7	15	3	8	Tethya	Central/South America
Vanilla phalaenopsis Rchb.f.	15	15	4	5	Tethya	Africa
Vanilla polylepis Summerh.	12	13	0	0	Tethya	Africa
Vanilla griffithii Rchb.f.	7	10	1	4	Tethya	Asia
Vanilla borneensis Rolfe	8	9	2	2	Tethya	Asia
Vanilla claviculata Sw.	6	9	3	6	Tethya	Central/South America
Vanilla crenulata Rolfe	9	9	1	1	Tethya	Africa
Vanilla humblotii Rchb.f.	9	9	2	4	Tethya	Africa
Vanilla albida Blume	7	7	3	4	Tethya	Asia
Vanilla perrieri Schltr.	5	6	1	3	Tethya	Africa
Vanilla kinabaluensis Carr	3	5	2	4	Tethya	Asia
Vanilla poitaei Rchb.f.	4	5	2	3	Tethya	Central/South America
Vanilla wightii Lindl.	5	5	1	1	Tethya	Asia
Vanilla africana Lindl.	4	4	0	0	Tethya	Africa
Vanilla decaryana H.Perrier	4	4	1	2	Tethya	Africa
Vanilla havilandii Rolfe	2	3	2	3	Tethya	Asia
Vanilla annamica Gagnep.	2	2	0	0	Tethya	Asia
Vanilla somae Hayata	1	2	0	0	Tethya	Asia
Vanilla walkeriae Wight	2	2	0	0	Tethya	Asia
Vanilla yersiniana Guillaumin	2	2	1	1	Tethya	Asia
Vanilla abundiflora J.J.Sm.	1	1	1	1	Tethya	Asia
Vanilla atropogon Schuit.	1	1	1	1	Tethya	Asia
Vanilla grandifolia Lindl.	1	1	0	0	Tethya	Africa
Vanilla raabii Ormerod	1	1	0	0	Tethya	Asia
Vanilla ramosa Rolfe	1	1	1	3	Tethya	Africa
Vanilla siamensis Rolfe	1	1	0	0	Tethya	Asia
Vanilla inodora Schiede	4	7	2	2	Membranacea	Central/South America
Vanilla costaricensis Soto	4	4	1	4	Membranacea	Central/South America
Vanilla mexicana Mill.	4	4	2	2	Membranacea	Central/South America
Vanilla angustipetala Schltr.	2	2	0	0	Membranacea	South America
Vanilla sarapiquensis Soto	1	1	1	1	Membranacea	Central/South America
sp./hybrid	6	24	5	118		
spp.	41	156	10	614		
Total	**221**	**2126**	**18**	**1866**		

[1]Sources: FAO WIEWS (www.fao.org/wiews/en/), GBIF (www.gbif.org/), BGCI (www.bgci.org/), and the 2020 survey.

Annex III. Institutions that participated in the strategy development

Institutions that participated in the strategy development via the survey questionnaire, interviews or feedback on the draft strategy.

Institution	Location	Country	Website	Survey	Inter-view	Feedback on draft strategy
Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Biological Resources Center Vatel	Saint Pierre	Reunion	intertrop.antilles.inra.fr/Portail/	✓	✓	✓
Tropical Research and Education Center (TREC) of the Institute of Food and Agricultural Sciences (IFAS), University of Florida (UF)	Homestead, Florida	USA	www.ufl.edu/ or trec.ifas.ufl.edu/	✓	✓	✓
Orquidario del Centro de Investigaciones Tropicales/Universidad Veracruzana	Xalapa Veracruz	Mexico	www.uv.mx/citro/infraestructura/orquidario/	✓	✓	✓
Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP)	Martínez de la Torre, Veracruz	México	www.inifap.gob.mx	✓		
FOFIFA, Station Régionale de Recherche	Ambohitsara, Antalaha	Madagascar	www.fofifa.mg	✓		
INSEFOR, Universidad Nacional de Costa Rica	Heredia, Costa Rica	Costa Rica	www.una.ac.cr	✓		✓
Corridgeree Belize Ltd	Silk Grass, Stann Creek District	Belize	www.corridgeree.com	✓		✓
Fundación Acción Social para el Desarrollo de la Costa Caribe de Nicaragua - FASDECCAN	Prinzapolka - Alamikamba	Nicaragua		✓		✓
Estación Experimental de Orquídeas de la Familia Archila	Cobán, Alta Verapaz	Guatemala		✓		
Montreal Botanical Garden	Montreal, Quebec	Canada		✓		✓
Kew Gardens, Millennium Seed Bank Project, Seed Conservation Department, Royal Botanic Gardens	Kew, Wakehurst Place	UK	www.kew.org/wakehurst/whats-at-wakehurst/millennium-seed-bank	✓		✓
Gothenburg Botanical Garden	Gotheburg, Sweden	Sweden	www.botaniska.se/en	✓		✓
Marie Selby Botanical Gardens	Sarasota, Florida	USA	www.selby.org	✓		
Jardín Botánico Lankester, Universidad de Costa Rica	Paraíso, Cartago	Costa Rica		✓		
Longwood Gardens	Kennett Square, Pennsylvania	USA	longwoodgardens.org	✓		
Nancy Botanical Garden / Jardin botanique du Montet / Jardin Botanique Jean-Marie Pelt	Villers-lès-Nancy	France	jardinbotaniquedenancy.eu/en/accueil/	✓		✓
Universität Bayreuth, Ökologisch-botanischer Garten	Bayreuth	Germany	obg.uni-bayreuth.de	✓		
Muséum national d'Histoire naturelle	Paris	France	www.mnhn.fr	✓		✓
Nicola S. Flanagan, Department of Natural Sciences and Mathematics, Pontificia Universidad Javeriana - Cali	Cali	Columbia			✓	✓
Minoo Divakaren, Dept of Botany, Providence Women's College	Kerala	India				✓
Sustainable Vanilla Initiative, Sustainable Food Lab	Hartford Vermont	USA			✓	
Botanical Gardens Conservation International	Richmond	UK				
Unilever UK Central Resources Limited	Bedford	UK			✓	
Symrise AG	Holzminden	Germany			✓	

Annex IV. Complete list of Vanilla species

Vanilla species	Section	Region of origin
Vanilla planifolia Andrews	Xanata	Central/South America
Vanilla pompona Schiede	Xanata	Central/South America
Vanilla odorata C.Presl	Xanata	Central/South America
Vanilla insignis Ames	Xanata	Central/South America
Vanilla phaeantha Rchb.f.	Xanata	Central/South America
Vanilla x tahitensis J.W. Moore	Xanata	Central/South America
Vanilla hartii Rolfe	Xanata	Central/South America
Vanilla dressleri Soto	Xanata	Central/South America
Vanilla palmarum Salzm.	Xanata	South America
Vanilla chamissonis Klotzsch	Xanata	South America
Vanilla karen-christianae Karremans	Xanata	Central/South America
Vanilla trigonocarpa Hoehne	Xanata	Central/South America
Vanilla appendiculata Rolfe	Xanata	South America
Vanilla carinata Rolfe	Xanata	South America
Vanilla cobanensis Archila	Xanata	Central/South America
Vanilla bicolor Lindl.	Xanata	Central/South America
Vanilla helleri A.D.Hawkes	Xanata	Central/South America
Vanilla capixaba Fraga	Xanata	South America
Vanilla columbiana Rolfe	Xanata	South America
Vanilla corinnae Sambin	Xanata	South America
Vanilla cribbiana Soto	Xanata	central/South America
Vanilla dubia Hoehne	Xanata	South America
Vanilla duckei Huber	Xanata	south America
Vanilla dungsii Pabst	Xanata	South America
Vanilla espondae Soto	Xanata	South America
Vanilla fimbriata Rolfe	Xanata	South America
Vanilla hostmannii Rolfe	Xanata	South America
Vanilla javieri Bar.-Colm.	Xanata	South America
Vanilla labellopapillata A.K.Koch	Xanata	South America
Vanilla marowynensis Pulle	Xanata	South America
Vanilla paulista Fraga	Xanata	South America
Vanilla penicillata Garay	Xanata	South America
Vanilla ribeiroi Hoehne	Xanata	South America
Vanilla rivasii Molineros	Xanata	South America
Vanilla ruiziana Klotzsch	Xanata	South America
Vanilla sprucei Rolfe	Xanata	South America
Vanilla vellozoi Rolfe	Xanata	South America
Vanilla weberbaueriana Kraenzl.	Xanata	south America
Vanilla imperialis Kraenzl.	Tethya	Africa
Vanilla madagascariensis Rolfe	Tethya	Africa
Vanilla aphylla Blume	Tethya	Asia
Vanilla barbellata Rchb.f.	Tethya	Central/South America
Vanilla roscheri Rchb.f.	Tethya	Africa
Vanilla dilloniana Correll	Tethya	Central/South America
Vanilla phalaenopsis Rchb.f.	Tethya	Africa

Vanilla species	Section	Region of origin
Vanilla polylepis Summerh.	Tethya	Africa
Vanilla griffithii Rchb.f.	Tethya	Asia
Vanilla borneensis Rolfe	Tethya	Asia
Vanilla claviculata Sw.	Tethya	Central/South America
Vanilla crenulata Rolfe	Tethya	Africa
Vanilla humblotii Rchb.f.	Tethya	Africa
Vanilla albida Blume	Tethya	Asia
Vanilla perrieri Schltr.	Tethya	Africa
Vanilla kinabaluensis Carr	Tethya	Asia
Vanilla poitaei Rchb.f.	Tethya	Central/South America
Vanilla wightii Lindl.	Tethya	Asia
Vanilla africana Lindl.	Tethya	Africa
Vanilla decaryana H.Perrier	Tethya	Africa
Vanilla havilandii Rolfe	Tethya	Asia
Vanilla annamica Gagnep.	Tethya	Asia
Vanilla somae Hayata	Tethya	Asia
Vanilla walkeriae Wight	Tethya	Asia
Vanilla yersiniana Guillaumin	Tethya	Asia
Vanilla abundiflora J.J.Sm.	Tethya	Asia
Vanilla atropogon Schuit.	Tethya	Asia
Vanilla grandifolia Lindl.	Tethya	Africa
*Vanilla raabi*i Ormerod	Tethya	Asia
Vanilla ramosa Rolfe	Tethya	Africa
Vanilla siamensis Rolfe	Tethya	Asia
Vanilla acuminata Rolfe	Tethya	Africa
Vanilla andamanica Rolfe	Tethya	Asia
Vanilla bakeri Schltr.	Tethya	Central/South America
Vanilla chalotii Finet	Tethya	Africa
Vanilla coursii H.Perrier	Tethya	Africa
Vanilla cucullata Kraenzl.	Tethya	Africa
Vanilla decesareae Ormerod	Tethya	Asia
Vanilla diabolica P.O'Byrne	Tethya	Asia
Vanilla francoisii H.Perrier	Tethya	Africa
Vanilla giulianettii F.M.Bailey	Tethya	Asia
Vanilla hallei Szlach.	Tethya	Africa
Vanilla heterolopha Summerh.	Tethya	Africa
Vanilla kaniensis Schltr.	Tethya	Asia
Vanilla kempteriana Schltr.	Tethya	Asia
Vanilla marmoreisense Soto	Tethya	Central/South America
Vanilla montana Ridl.	Tethya	Asia
Vanilla moonii Thwaites	Tethya	Asia
Vanilla nigerica Rendle	Tethya	Africa
Vanilla norashikiniana Go	Tethya	Asia
Vanilla ochyrae Szlach.	Tethya	Africa
Vanilla ovalis Blanco	Tethya	Asia
Vanilla palembanica Teijsm.	Tethya	Asia
Vanilla platyphylla Schltr.	Tethya	Asia

Vanilla species	Section	Region of origin
Vanilla ramificans J.J.Sm.	Tethya	Asia
Vanilla sanjappae Rasingam	Tethya	Asia
Vanilla seranica J.J.Sm.	Tethya	Asia
Vanilla seretii De	Tethya	Africa
Vanilla sumatrana J.J.Sm.	Tethya	Asia
Vanilla utteridgei J.J.Wood	Tethya	Asia
Vanilla wariensis Schltr.	Tethya	Asia
Vanilla zanzibarica Rolfe	Tethya	Africa
Vanilla inodora Schiede	Membranacea	Central/South America
Vanilla costaricensis Soto	Membranacea	Central/South America
Vanilla mexicana Mill.	Membranacea	Central/South America
Vanilla angustipetala Schltr.	Membranacea	South America
Vanilla sarapiquensis Soto	Membranacea	Central/South America
Vanilla acuta Rolfe	Membranacea	south America
Vanilla arcuata Pansarin	Membranacea	South America
Vanilla armoriquensis Damian & Mitidieri	Membranacea	South America
Vanilla bertoniensis Bertoni	Membranacea	South America
Vanilla bradei Schltr.	Membranacea	South America
Vanilla dietschiana Edwall	Membranacea	South America
Vanilla edwallii Hoehne	Membranacea	South America
Vanilla guianensis Splitg.	Membranacea	South America
Vanilla methonica Rchb.f.	Membranacea	South America
Vanilla organensis Rolfe	Membranacea	South America
Vanilla oroana Dodson	Membranacea	South America
Vanilla parvifolia Barb.Rodr.	Membranacea	South America
Vanilla verrucosa Hauman	Membranacea	South America

RECOMMENDED CITATION

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