Meeting the Challenges of
Global Climate Change and Food Security through Innovative Maize Research

Proceedings of the 3rd National Maize Workshop of Ethiopia
April 18-20, 2011; Addis Ababa, Ethiopia

Editors: Mosisa Worku, S. Twumasi-Afriyie, Legesse Wolde, Berhanu Tadesse, Girma Demisie, Gezehagn Bogale, Dagne Wegary, and B.M. Prasanna

EARI
Ethiopian Institute of Agricultural Research

CIMMYT
International Maize and Wheat Improvement Center

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Ethiopian Institute of Agricultural Research (EIAR)

CIMMYT

International Maize and Wheat Improvement Center

The International Maize and Wheat Improvement Center, known by its Spanish acronym, CIMMYT® (www.cimmyt.org), is a not-for-profi t research and training organization with partners in over 100 countries. The center works to sustainably increase the productivity of maize and wheat systems and thus ensure global food security and reduce poverty. The center's outputs and services include improved maize and wheat varieties and cropping systems, the conservation of maize and wheat genetic resources, and capacity building. CIMMYT belongs to and is funded by the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org) and also receives support from national governments, foundations, development banks, and other public and private agencies. CIMMYT is particularly grateful for the generous, unrestricted funding that has kept the center strong and effective over many years.

Correct citation: Worku, M., Twumasi-Afriyie, S., Wolde, L., Tadesse, B., Demisie G., Bogale, G., Wegary, D. and Prasanna, B.M. (Eds.) 2012. *Meeting the Challenges of Global Climate Change and Food Security through Innovative Maize Research*. *Proceedings of the Third National Maize Workshop of Ethiopia.* Mexico, DF: CIMMYT.

AGROVOC descriptors: Maize; Germplasm; Plant breeding; Food security; Food production; Climatic change; Technology transfer; Innovation adoption; Research; Soil fertility; Crop management; Seed production; Extension activities; Farming systems

Additional Keywords: CIMMYT

AGRIS Category Codes: F30 Plant Genetics and Breeding
E10 Agricultural Economics and Policies

Dewey Decimal Classification: 633.15363

ISBN: 978-970-648-184-9

Cover photograph: CIMMYT files

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Sponsors of the Third National Maize Workshop of Ethiopia

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- Ethiopian Seed Enterprise
- Haramaya University
- Syngenta Agri Services PLC
- General Chemicals and Trading PLC
- Oromia Seed Enterprise
- Ano Agro-Industry

Products displayed during the Third National Maize Workshop of Ethiopia

1. Ethiopian Institute of Agricultural Research
   - Samples of improved maize varieties for mid-altitude, highland and low moisture stress areas
   - Farm implements (moldboard plough, tie ridger, row planter, maize sheller, corn cob carbonizer, chopper, etc)
2. Ethiopian Health and Nutrition Research Institute
   - Different local dishes prepared from quality protein maize (*injera*, bread, porridge, *anebabero*, quality protein maize (QPM) *besso*, QPM *siljo*, *kinche*, *kitta* and others)
3. FAFFA
   - Famix, Corn flakes
4. Guts Agro industry
   - Lembo biscuits, Famix
5. Oromia Farmers' Unions Federation Maize Processing Plant
   - Maize flour, grits (three products from germ, pericarp and endosperm)
6. High Take Trading House
   - Organic hermetic storage cocoon
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   - Different herbicides, insecticides and fungicides
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   - Different insecticides and fungicides
10. Health Care Food Manufacturers, PLC
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11. Alema PLC
    - Different feeds prepared from maize

Welcome Address

***Solomon Assefa*[1]**

[1] Director General, Ethiopian Institute of Agricultural Research, Ethiopia

Your Excellency Ato Wandirad Mandefro, State Minister, Ministry of Agriculture (MoA), distinguished scientists, invited guests, participants, ladies and gentlemen, it is a pleasure and an honor for me to welcome all of you to the Third National Maize Workshop of Ethiopia.

The Ethiopian Institute of Agricultural Research (EIAR) is mandated to generate and disseminate agricultural technologies to end-users in collaboration with various stakeholders. The National Maize Research Project is among the strongest projects in the Ethiopian agricultural research system. The technologies developed/recommended by the project over the years have played a great role in increasing maize productivity and production, and improving the livelihoods of farmers. I would like to appreciate all national and international scientists and other stakeholders who contributed to the development and dissemination of these technologies. EIAR will continue to work in partnership with the Consultative Group of International Agricultural Research (CGIAR) centers and other stakeholders in maize research and development for the benefit of our farmers.

EIAR is responsible for compiling and publishing information generated by the research system in a usable form. One means of compiling this information is through organizing various conferences and workshops and publishing the proceedings. The National Maize Research Project of Ethiopia has a well-established tradition of conducting decadal workshops on maize research, development and utilization. The first and second workshops were held in 1992 and 2001, respectively. The articles published in the proceedings are good sources of information for researchers, development agents, farmers, industry groups and other stakeholders. As I have been informed by the organizers, over 40 papers will be presented during this workshop in areas of maize research, seed production, extension and utilization. The proceedings will be published immediately in hard and soft copies in collaboration with CIMMYT and will be a valuable source of information for all stakeholders.

Ladies and gentlemen, as you know, the Federal Democratic Republic of Ethiopia has prepared and launched a Growth and Transformation Plan (GTP) for the country for the next five years, 2011–2015. At the end of this period, agricultural production and productivity in Ethiopia is expected to increase by at least two-fold. As maize is one of the major crops grown across almost all agro-ecologies of the country, the contribution of maize in the realization of this plan and food security is great. I believe the discussions and recommendations you are making during this workshop will contribute greatly to the success of this plan.

Finally, I would like to thank the workshop organizing committee, whose contributions have made it possible for this workshop to take place. I am also grateful to CIMMYT, EIAR/Sustainable Intensification of Maize-

Legume cropping systems for food security in Eastern and Southern Africa (SIMLESA) Project, OXFAM-America, Sasakawa Global 2000 (SG2000), Pioneer Hi-Bred Seeds Ethiopia PLC, Ministry of Agriculture (MoA)/Rural Capacity Building Project (RCBP), Agri-CEFT, Ethiopian Seed Enterprise, Haramaya University, Syngenta Agri Services PLC, General Chemicals and Trading PLC, Oromia Seed Enterprise and Ano Agro-industry PLC for sponsoring this important workshop. My sincere appreciation also goes to all participants, particularly international scientists who have devoted their precious time to join us and share their experiences.

Thank you!

Opening Address

***Wondirad Mandefro*[1]**

[1] State Minister, Ministry of Agriculture, Ethiopia

Workshop participants, invited guests, ladies and gentlemen, on behalf of the Ministry of Agriculture and myself, it gives me great pleasure to join you this morning at the opening of the Third National Maize Workshop of Ethiopia.

As we all know, agriculture is the mainstay of the Ethiopian economy. More than 83% of the population lives in rural areas relying on agriculture as the main source of livelihood. Agriculture also accounts for 43% of the gross domestic product (GDP), about 90% of the export earnings and 80% of the national employment.

The Economic Development Policy of Ethiopia has given the highest priority to agriculture under the overarching economic policy of the Agricultural Development Led Industrialization (ADLI). Since the last half of the last century, agriculture, which used to be plentiful providing a decent living to Ethiopians, has been challenged through various natural and manmade causes. Recurrent drought, resulting in severe famine, was the symbol until these days. Since the last decade and particularly the last eight years we have managed to sustainably grow the agricultural sector, particularly the crops sector, with an average of 8% annual growth, and this past season 12.5%. This is the result of the policies put in place and commitments made by the government and farming communities. By and large, it made the most significant contribution to the overall economic growth obtained in the decade.

The government of Ethiopia has launched the five year Growth and Transformation Plan (GTP) with the major objective of achieving accelerated, sustained, and people centered economic development, thus fulfilling the Millennium Development Goals (MDGs) by 2015. Moreover, it is also a bridge towards becoming a middle income country by 2025. The fundamentals of Ethiopia's agricultural development strategy clearly outlined in the Rural Development Policy and Strategy (RDPS) are:

1. Adequately strengthen human resource capacity and its effective utilization
2. Ensure prudent allocation and use of existing land
3. Adaptation of development path compatible with different agro-ecological zones
4. Specialization, diversification and commercialization of agricultural production
5. Integration of development activities with other sectors, and
6. Establishment of an effective agricultural marketing system.

The GTP aims at transforming the whole economic sector at large, including the agriculture sector, towards surplus-producing market-oriented small-holder agriculture. The plan has been supported by policies as articulated in the RDPS. The strategy rests primarily upon three basic principles; (i) staple crops production (with production surpluses to feed the urban consumers and supply raw materials for emerging agriculture-based industries); (ii) increase demand for non-agricultural commodities (to fuel the growth of the non-agriculture rural sub-sector), and (iii) the release of labor from agriculture to non-agricultural areas (allowing growth of urbanization by migration of rural people to urban areas, thus, decreasing demographic pressure on the land).

Ladies and gentlemen, increases in agricultural production have made important contributions to the recent high economic growth recorded in the country. The recent growth in the agriculture sector has been achieved by use of improved agricultural technologies which includes improved seeds, chemical fertilizers and other improved management practices, and an expansion of cultivated area.

Among the major crops grown in Ethiopia, cereal crops constitute the lion's share of the domestic food supply, income generation and source of employment. However, domestic cereal production is insufficient to cover requirements and therefore a substantial amount of cereals have to be imported. In order to feed the projected 115 million population of Ethiopia by 2015, investing in agricultural research and development becomes a compelling necessity. In addition to focusing on market oriented high value commodities, the Ethiopian government has placed high priority on accelerating grain production for achieving food self-sufficiency and security. The fact that Ethiopia grows both the high-profile cereals, such as maize and wheat, and locally important resilient and indigenous cereals, such as *tef*, sorghum and millets provides a wide scope towards tackling food shortage in a sustainable manner.

During the 2010/11 main cropping season, cereal crops were cultivated on 9.906 million ha of land producing 17.2 million t of grain. These account for about 82.3% and 87.7% of the total area and production of food grains in the country, respectively. Of the cereal crops, maize ranks second to *tef* in area coverage and first in total production. The per capita consumption of maize in Ethiopia is about 50 kg $year^{-1}$. In the short and medium term, maize will remain the most strategic crop in the country. Hence, with the anticipated doubling of total production in 2015, as stipulated in the GTP, the contribution of maize as a source of increased productivity is vital. The current average productivity of 2.3 t ha^{-1} needs to triple, if not quadruple, to assist the average productivity of the other major food crops.

So far, maize has been grown in Ethiopia for direct consumption, however, with the growth of the Ethiopian economy and income of the people, the demand for maize as feed and as an industrial raw material is expected to increase. This requires a further increase in maize productivity and production in the country through popularization and expansion of existing and newly generated technologies.

Ladies and gentlemen, during the past decades significant achievements have been recorded by maize research in the country. This has contributed to the increment of total maize production and productivity. However, more effort is required in the future in maize research, seed production, marketing and processing to realize the agricultural GTP. Maize has contributed significantly to the national agricultural extension program for quick results via hybrid varieties giving quick return to farmers. In addition, there are a number of national and international stakeholders working together with national maize research teams around the country. This trend has to continue and be further strengthened for better results.

During this workshop I hope valuable presentations and discussions will be made in different areas of maize research and development which will contribute to the GTP goals. I appreciate the presence of different local and international scientists and I hope they will contribute greatly towards the success of this workshop. I also expect your active participation and valuable recommendations will help the end users.

Finally, I wish you all the best in your deliberations and I declare this workshop open!

Thank you very much.

Keynote Address

***Benti Tolessa*[1]**

[1] Anno Agro-industry, Bako, Ethiopia.

Mr. Chairman, workshop participants, and colleagues, maize research has a history of 60 years in this country. Research outputs and significant achievements made during those years are well documented in the proceedings of the First and Second National Maize Workshops and there is no need to explain them any further. The 1980s through 2000s, however, was a very special period for our maize research effort for many reasons. It was in the 1980s that most of the agronomic and crop production and protection practices were determined for the different maize growing environments of Ethiopia. This period is also well remembered for the initiation of strong on-farm research, formulation of research and extension linkages and moisture conservation techniques for the dry environments. It was also in the mid-1980s that a strong foundation was laid for the hybrid maize breeding program in Ethiopia. With local germplasm collections and introductions from CIMMYT, and other countries, the National Maize Research Program was able to assemble useful germplasm for the hybrid program which resulted in the release of four hybrids by 1995. Technical and material support, and germplasm obtained from CIMMYT was crucial for the release of these superior hybrid maize technologies and we are thankful to CIMMYT for their assistance. When these four hybrids were released, we were not clear on what type of technology transfer and extension mechanism to use to get the hybrids to farmers' fields. Luckily, the release of the hybrids coincided with the initiation of the Sasakawa Global 2000 (SG2000) Extension Program in Ethiopia. Therefore, the success of our hybrid maize and other maize technologies is also due to the vigorous extension activity undertaken by the SG2000 in 1993 and adoption by the Ethiopian extension program in 1996. Just to remind you, the Ethiopian SG2000 Extension Program was born during the First National Maize Workshop, convened in 1992. It was during this workshop that the late Mr. Takele Gebre and other senior agricultural research and extension experts met Dr. Markos Quinones, Tanzania SG2000 Country Director at the time and developed the successful SG2000 extension strategy for Ethiopia.

The release and countrywide adoption of most of the hybrids also served as a strong stimulus for subsequent releases of superior maize technologies in 2000 and the years to follow. Maize germplasm development from 2000 to the present day can be summarized as follows: The 2000s were marked by the release of quality protein maize (QPM) varieties. These maize varieties, in addition to higher yields, are rich in two limiting essential amino acids in maize thus improving food quality for our people. From 2000 to 2011 significant breakthroughs in maize research were realized by the release of seven low moisture stress tolerant open-pollinated varieties (OPVs). It was also during this time that the highland maize breeding program was able to release four superior maize hybrids, one of the hybrids being a conversion of BH660 to QPM. Because of these technologies, maize is now moving to the highlands of Ethiopia where maize has been a minor crop in the past. In addition, a number of OPVs and hybrids developed by the National Maize Research Program and private seed companies have been released in the mid-altitude sub-humid areas. However, most of the varieties are not aggressively popularized and adopted by farmers in their adaptation domains.

In general, shifts in commercial maize production from OPVs to hybrids in 1994 and thereafter account for the sharply improved national average yields of maize. The national average yield of maize 15 years ago was 1.5 t ha^{-1}; today it is about 2.3 t ha^{-1}. The question now is, what should be the next hybrid maize breeding strategy and research priority to increase maize yield to, at least, 5.0 t ha^{-1} in the next ten years? This workshop needs to seek answers to this question by analyzing research and extension gaps and setting priorities so that a suitable germplasm base and breeding strategy as well as appropriate technology transfer system are identified and implemented for each maize growing environment to enable us to meet our target of 5 t ha^{-1} by the year 2020.

The introduction of hybrid seed into the production system has also triggered the emergence and establishment of successful seed industries in this country. Ten years ago, there were only two seed companies; the Ethiopian Seed Enterprise and Pioneer Hi-Bred Seeds Company Ethiopia PLC. Today we have more than 30 private seed companies of different capacity and several farmers' cooperatives that produce hybrid maize seed in Ethiopia. Thus, hybrid maize has created private seed companies and several job opportunities for the Ethiopian people.

I would like to congratulate all of the maize researchers, seed producers and extension staff for the superior maize technologies you have delivered to Ethiopian maize farmers so that they can become food self-sufficient and improve their standard of living. Congratulations to all!

Improved maize technologies developed so far are an important driving force for change in maize production in Ethiopia. Comments we often hear now, however, refer to a homogeneity problem caused by growing BH660 on large areas and the unavailability of diverse types of BH660 series types of hybrids suitable for the transitional highlands. Therefore, I suggest the following points to overcome this problem.

My preliminary crop assessment in the western transition highland part of the country in August 2010 reveals that a single hybrid (BH660) is planted on large scale revolutionizing maize production in a manner not seen previously in this country. I am pleased to see such country-wide acceptance and adoption of BH660 by Ethiopian maize farmers. The use of a single hybrid across a wide area, however, poses serious concern in terms of disease and pest outbreak due to possible mutations of pathogens that can take place when a single hybrid is grown in such a large area. It is therefore important to invigorate our breeding effort towards developing genetically diverse types of maize varieties so that the homogeneity problem does not pose a serious disease problem in maize production. The recently released varieties, including BH661, are an important step forward in our maize breeding effort and what is left now is a strong popularization effort for the varieties to reach farmers' fields.

Maize hybrids such as BH540 and BH660 series under commercial use in Ethiopia involve inbred lines with some level of heterozygosity when they were released. This was done to ensure good vigor and high yield potential compared to the long term inbred lines development approach used extensively in the USA and other countries. This aspect of heterozygosity should be taken note of in the seed multiplication of the lines because maintaining the lines in a manner in which fixed lines are maintained will result in a loss of variability and vigor leading to poor performance of the hybrids. Cognizant of this, maize breeders from our national program are using the suitable methodologies for breeder seed production and parental line maintenance so that the level of heterozygosity in the inbred lines is not altered from year to year and significant gene frequency changes do not occur. Although I am happy with the current government initiative to give the parental lines of the released hybrids to seed companies, care should be taken in the method of maintaining these kinds of inbred lines and production of their breeder seeds. Therefore, they must take the appropriate guidelines from research centers along with the breeder seeds. Unless they strictly follow the guidelines for maintaining the parental lines and production of early generation seeds, we may soon run into serious problems. The research centers should also describe how often seed companies should get fresh parental seeds from them and the requirements of stringent seed inspection and regulation techniques required to maintain the parental lines.

Improved management and protection packages unlock the high yield potential of hybrids. Yield superiority of hybrids can be expressed only when grown under optimum management and protection practices. Our agronomists and protection staff from different research centers have investigated management practices for the released maize varieties such as weed control, population density, pest and disease control and crop storage and processing technologies. Therefore, all the available management technologies should be channeled to the farmers' field along with the improved varieties to realize sustainable increases in maize productivity and production.

Finally, I would not like to pass without mentioning the contribution of the pioneer maize researchers, including the late Dr. J. Singh who passed away while on duty on maize research in Ethiopia.

Thank you!!

Values That Foster Effectiveness of Partnership for Agricultural Innovation: Substantiation to EIAR–CIMMYT Strap

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Introduction

Agriculture has been the foundation of Ethiopian economy and part of the history, culture, knowledge system and way of life for centuries. It contributes a great proportion to the gross national product (GNP) and thus its improvement stabilizes the economy, society and politics of the country. Almost 80% of the country's population are living in rural areas and are directly or indirectly linked to agriculture for their livelihood. According to recent data, agriculture accounts for 41% of the gross domestic product (GDP) and contributes to nearly 90% of Ethiopia's export earnings. However, the agricultural export economy is constantly subjected to the caprices of the weather; therefore, agricultural production is geared towards domestic consumption.

The Ethiopian government has expressed its commitment to support agricultural research and technology development to accelerate agricultural productivity (FDRE, 2002, 2001). Besides the staple food crops, emphasis is being made on developing improved technologies for crops of high demand in domestic and international markets in order to achieve food security. Equal emphasis is being given to address parallel, but complex, problems such as conservation and sustainable use of natural resources, reclamation of degraded soils, and enhancing product quality and food safety (FDRE, 2011).

Agricultural research and technological improvements are, and will continue to be, prerequisites for increasing agricultural productivity and generating income for farmers and the rural work force. Investment in innovative agriculture is not only expected to improve local food production through an increased quantity, quality and diversity of food, but also used as an option to bring a shift towards resource efficiency and the next Green Revolution to address environmental problems. Like many other countries in the world, Ethiopia also focuses on the use of science-based agricultural technology to improve agricultural production (more specifically crop production) through increased income in the rural community. While the total agricultural production in the country has increased in the last 6 years, the contribution of agriculture has decreased from 47.4% in 2005 to 41.0% in 2010 (FDRE, 2011).

As the problems within the agricultural sector are becoming complex, no one single institution alone can fully address the difficult issues of implementing sustainable agricultural development objectives in developing countries. Rather, an alliance that brings together the necessary complementarities to form more complete solutions is preferable. Generally, the national agricultural research systems (NARS) in developing countries are small in size and highly fragmented, have low levels of professional training, poor incentive structures, high staff turnover, lack financial independence, have weak links with farmers and poor coordination among components (Sumberg, 2004). Therefore, there is an obvious need for researchers to not only form strategic partnerships and work as multi-disciplinary research teams, but also to form cost effective partnerships with other stakeholders including producers, community groups, nongovernmental organizations and the private sector (Smith, 2004). Strategic alliances between institutions, businesses, government and civil society are a growing feature of both developed and emerging economies (Warner, 2002).

A large number of research partnership activities have been undertaken over a long period of time within the Ethiopian Agricultural Research System (EARS). Such past activities included development efforts with the Consultative Group on International Agricultural Research (CGIAR), United Nations (UN), and regional and sub-regional organizations, both on formal and informal bases. In retrospect, research for development by EARS through partnership has proved beneficial and there is a need to strengthen the collaboration in order to further enhance the meaningful relationship between NARS entities and national, regional, sub-regional and international partners. In this paper, the longstanding, 30 year EARS–CIMMYT partnership will be analyzed to elucidate such partnerships for agricultural development. The paper looks into the issues of agriculture technology development through partnership in Ethiopia with different stakeholders that benefit the Ethiopian farmers and the gains obtained through the longstanding Ethiopian Institute of Agricultural Research (EIAR)–CIMMYT partnership.

The Ethiopian Agricultural Research System

The present EARS is mainly composed of the EIAR, regional agricultural research institutes (RARIs) and higher learning institutions (HLIs). In addition, some public and private companies also participate directly or indirectly in research activities related to agriculture (EIAR, 2009). While the concepts, theories, tools and techniques were developed at the international level and subsequent changes in development paradigm have had an influence on developing national agricultural policies and technologies all over the world, the federal structure of the government of Ethiopia highly influenced the institutional structures of the NARS.

The mandates of the EIAR, RARIs and HLIs are that the three principal components of the system complement each other. EIAR is responsible for the running of the federal research centers. It mainly concentrates on problems of national importance, with some focus on regional problems wherever the local research infrastructure is not yet fully developed. In addition to conducting research at its federal centers, it is charged with the responsibility for providing the overall coordination of agricultural research countrywide and advising the government on agricultural research policy formulation. Regional problems are handled principally by RARI. RARIs are administered by the regional state governments (Adefris and Solomon, 2010; EIAR, 2009). Higher learning institutions are accountable to the Federal Ministry of Education and carry out strategic research both as student theses and on a part-time basis by the teaching staff.

Essential features of the EARS are its philosophy of service to agriculture and the rural community, and its emphasis on projects that are directly and immediately related to solving the social and economic problems of the countryside (Adefris and Solomon, 2010). More recently, the concepts of proven technologies, best-bet and scaling out/up have gained importance in the country by moving the system beyond the on-station and on-farm technology development and demonstration, towards a wider reach of productivity packages to remote and un-addressed areas.

Currently, the EARS are comprised of 63 research centers and more than 140 sub-centers and testing sites located across various agro-ecological zones. The research centers vary in their experience, human resources, facilities and other capacities. The RARIs impact the NARS structure through the significance of the sheer numbers of their research centers (Table 1). They have research centers distributed at various different agro-ecological zones (EIAR, 2009). A clear advantage of such an extensive system of centers and sub-centers is its ability to reach deep into the hinterland and seek out researchable problems.

Table 1. Research centers of the Ethiopian Agricultural Research Institutes (EARIs).

Research Institute	No. of Research Centers
Ethiopian Institute of Agricultural Research	14
Oromia Agricultural Research Institute	17
Amhara Agricultural Research Institute	8
Tigrai Agricultural Research Institute	7
Somali Pastoral and Agropastoral Research Institute	6
Southern Region Agricultural Research Institute	5
Afar Pastoral and Agropastoral Research Institute	3
Gambela Agricultural Research Institute	3
Total	**63**

The Need for Partnership

A partnership is an arrangement where entities and/or individuals agree to cooperate to advance their interests. In both developed and emerging economies, strategic partnerships are necessary because it is increasingly clear that no one sector in society can solve complex problems and bring sustainable development on its own. Partnerships for sustainable development are relatively novel phenomena. They seek not to shift responsibility and risk from one party to another, but to share risks, pool resources and talents, and deliver mutual benefits (Warner, 2002). Moreover, research is an expensive venture and the great advances in scientific methodologies and technologies which are increasingly necessary to improve the ability of human kind to address challenges require working together with common vision and resource merging (ICRAF, 2008; ICRISAT, 2009).

The EARS has a universal objective of partnership: to create synergies with other organizations in order to reach common goals and objectives and support the country in availing appropriate technologies and knowledge to the needy small holder farmers. Through this broad objective, EARS is destined to achieve one or more of the following:

- Congregate opportunities provided by institutions and organizations with resources, experience and mandates that add to what is already available to understand and formulate relevant strategies, programs, projects and activities
- Perform research problem identification, research planning, technology adaptation/generation, evaluation, adoption, and impact assessment of innovations appropriate to the local conditions

- Shorten the duration of technology delivery through technology and knowledge introduction
- Reduce the cost of technology and knowledge generation
- Integrate exotic and indigenous knowledge and expertise into our work
- Promote local participation to advance science and technology
- Promote ownership of our work by other institutions, policy makers, non-government organizations (NGOs) and individuals

As most NARS in the developing countries are weak, they are not expected to function as effective innovation systems (Sumberg, 2004). The current trend of globalization necessitates that developing countries like Ethiopia participate in the 'global agricultural system', suggesting that this will only be achieved through the development of a strong national capacity as presented in 'centers of excellence', regional and international alliances and public–private partnerships. In Ethiopia, partnerships occur between the components of the EARS and NARS of different countries, universities, regional and international research organizations. The EARS partnerships have grown at different rates, with some being more active than others. EIAR has formed partnerships with various parties who would like to bring an impact to the rural livelihood of Ethiopia, but specifically with regional and international organizations that are mandated to carry out agricultural research for development. They have a legitimate stake in what the national agricultural system is doing. The EARS has a long history of collaboration with regional organizations (Association for Strengthening Agricultural Research in Eastern and Central Africa; ASARECA, BecA-ILRI), country based organizations (IDRC, CIDA, SIDA), international research centers (International Center for Agricultural Research in the Dry Areas; ICARDA, International Maize and Wheat Improvement Center; CIMMYT, International Crops Research Institute for the Semi-Arid-Tropics; ICRISAT, World Vegetable Research Center; ADVRC, International Institute of Tropical Agriculture; IITA, International Livestock Research Institute; ILRI etc) and UN organizations like the Food and Agriculture Organization (FAO) working and supporting agricultural research. Our direct collaboration with the so-called 'advanced research institutes' (ARIs) is quite limited. Such collaboration essentially includes Cornell University through training and advanced research undertakings that require sophisticated equipment and human resources. The south–south partnership with the NARS of countries like India, China, South Korea, and Brazil has begun but is limited only to visits and experience sharing.

The role of EARS is not only confined to developing new technologies on its own but also to facilitate the development of new technologies through external partnerships. It guides, facilitates, enables, monitors and promotes participatory and collaborative technology development.

The EIAR identified about 35 categories of local and foreign partner institutions (EIAR Business Process Reengineering documents, unpub., 2008) and the relationship with them could be categorized into the following:

- Budgetary
- Policy link and facilitative function
- Agricultural problem identification and technology validation
- Knowledge and technology generation
- Networking to organize resources and for technology generation and exchange
- Data and information provision
- Input and supply provision
- Organization
- Technology testing and validation
- Out- and up-scaling
- Feedback on the relevance of research
- Capacity development
- Information sharing and education

Non-formal partnerships such as student supervision, graduate and post-graduate student examination, experience sharing, and dissemination/public awareness groups are executed based on institutional or individual level partnership or collaboration.

Institutions of the EARS target foreign partnership for knowledge transfer, finished technologies, unfinished technologies, budgetary support, capacity development, skill development and experience sharing. By partnering, institutions of the EARS can offer the following advantages:

- Opening to partners for closer and direct reach and entrance to end-users; specifically farmers
- Identify impact-oriented researchable areas and targets
- Provide participatory research and development experience and methodologies
- Local solutions to specific agricultural problems
- Demonstration of practical viability of agro-ecological interventions ready to be scaled up
- Reduce research costs

- Translate research outputs into products
- Networks for technology generation and exchange
- Insure greater and more equitable participation of international and regional research stakeholders in Agricultural Research and Development (ARD) projects

The EARS Principles of Partnership

The EARS principles of partnership are to provide an insight into how the partnership is sought by the EARS, to effectively contribute to the achievement of the country's development and poverty reduction goals, as well as country specific Millennium Development Goals (MDG). Broadly, according to the Paris Declaration on Aid Effectiveness (2005), the Accra Agenda for Action (2008), the Joint Donors Principle for ARDP (2009), and the Comprehensive Africa Agriculture Development Programme (CAADP), development partners should be aligned to the national development plans and priorities to achieve better development results. Hence, principles of partnership in agricultural research for development focus on the process and modalities of achieving greater effectiveness in agriculture and rural development programs.

While the principles of the EARS partnership are based on the country's development policies and strategies and the above international agreements, assessing our own and other similar institutions' experience to address some of the challenges and the lessons learned contributed to formulating these principles. These values include:

1. Share a holistic common view of agricultural strategies and government policies through aligning desired outcomes with strategic priorities set by the country/institution as well as those of the partner to ensure mutual benefits.
2. Joint planning/planning at equal footing: Evenhandedness and mutual respect should be the basis of the relationships. Respect the diversity of ideas, institutional integrity, local conditions, processes etc. of partners needs to be adhered to. While all gained knowledge and resource is useful, joint planning ensures ownership which is critical to guarantee that the research project and activities are relevant and responsive to the needs of the ultimate users, and that the activities complement rather than duplicate activities of NARS and other organizations that are active in agricultural research.
3. Institutions/systems rather than individuals should be the basis of the partnership: The continuity and sustained generation of innovations can be assured when the partnership bases its footing on an institution/system rather than on individuals. Indeed, a legally binding partnership is made between institutions. Institutional recognition of the partnership creates a conducive institutional environment to access resources through protecting the distinct mandates and derives high-level managers' attention. This is specifically true in countries like Ethiopia where the research and development is dominated by public institutions.
4. The partnership should encourage complementarities in tasks and synergy of expertise: Defining responsibilities clearly based on comparative advantage and competence; better understanding and analyzing the special expertise and physical resource accessibility and availability leads to complementarities and joint responsibility for the targeted outcome and impact.
5. The partnership should bring investment in the area of capacity building. EARS has a longer-term mandate to serve as a sustainable technology and knowledge focal point. Therefore, the principal driver for the collaboration should not only be a short-term technological development benefit. As the long-term goal of EARS is self-reliance, capacity building requires special emphasis. For this to happen, the partnership has to include investments for strengthening the knowledge and skills of researchers, extension workers and farmers and building physical capabilities (vehicle, lab equipment, laboratories, greenhouses, etc) within the context of the agricultural innovation system.
6. Equity and transparency: The project planning and implementation has to boost equitable and mutually beneficial collaboration of EARS and the partners on agricultural research for development, ultimately contributing to food security and reduction of poverty in the country.
7. Partners have to foster institutional innovation through applying appropriate methods suitable for local conditions, including participatory research and integrated natural resource management approaches, and should contribute through applied research to the development of alternative institutional arrangements for technological development and delivery systems.

Formalization of Partnership In EIAR

EIAR formalize partnerships through signing Memorandums of Understanding (MoU) or Letters of Agreement (LoA) usually done by the Head of the Institution. Such agreements are usually general and mostly outline the intent of the collaboration rather than actual details. Copies of such documents are maintained by the offices of the signatories, the planning, monitoring and evaluation office (PMEO), the concerned directorate and the archive. As a follow-up to such agreements, specific project or activity-based agreements are signed. Such agreements describe the role and responsibilities of partners, intellectual property right (IPR) issues, the agreement period, financial aspects, and observance of international and local laws. In the case of EIAR, such signing is made by the head of the PMEO after the technical, financial and administrative issues are examined by the respective heads leading the research of that specific commodity, program and directorate. Copies of such agreements are maintained at the PMEO and with copies also forwarded to Purchase, Finance and Procurement Directorate at the EIAR headquarters level. The stamped copy of the MoU is sent to the implementing research centers and commodity leader.

EIAR Based Research Projects Undertaken in Partnership

In 2010, there were about 90 externally funded projects registered at EIAR research directories. Of these, 59 were crop-related projects (Table 2). The collaborators included private companies (local and foreign), CGIAR centers (CIMMYT, ICRISAT, International Potato Center; CIP, ICARDA and International Center for Tropical Agriculture; CIAT), international financial institutions such as the World Bank, National Agricultural Research Fund; NARF, Regional Agricultural Research Fund; RARF and International Fund for Agricultural Development; IFAD, foreign universities (Nebraska, Virginia, Ohio, Boston), Foundations (Bill and Meilinda Gates Foundation, McKnight, Rockefeller), Governmental institutions from the USA (United States Agency for International Development; USAID, United States National Science Foundation; USNSF), Japan (Japan International Cooperation Agency; JICA), Germany (Gesellschaft für Technische Zusammenarbeit; GTZ, German Federal Ministry for Economic Cooperation and Development; BMZ), Netherlands, Austria (Bundesministerium für Finanzen; BMF and Austrian Development Agency; ADA), Australia (Australian Centre for International Agricultural Research; ACIAR), International centers (International Development Research Center; IDRC, INTSORMIL, Biodiversity International) and the Generation Challenge Project (GCP). The Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) has been one of the most important sources of funding for agricultural research and development in Ethiopia. Thirteen research projects have been funded by ASARECA. The only UN based organization that had project based collaboration with EIAR was the United Nations Environment Programme (UNEP)/Global Environment Facility (GEF).

Table 2. Ethiopian Institute of Agricultural Research (EIAR) collaborative research projects.

No.	Focus	No.
1	EIAR general	4
2	Crop	59
3	Forestry	4
4	Livestock	8
5	Mechanization	1
6	Soil and water	14
	Total	90

In number, private company-based collaboration has exceeded the other categories. However, the financial support was small and the period of collaboration was also short. Mostly the public–private partnerships joint activities were focused on research products (variety, chemicals, bioagents) verification. The exemplary research for development collaboration with local institutions was what was done with Assela Malt factory and four local breweries. The project aimed at developing and extending malt barley technologies to boost malt barley production and productivity and bring self-reliance in malt for the local breweries. Based on a four year collaborative agreement, the malt and beer factories availed more than 1 million USD for research and development to the EARS. Of this, 60% was contributed by the malt factory while the four breweries contributed 10% each. On the other hand, among the international organizations, the longstanding partnership with CIMMYT has some special features to mention.

EIAR–CIMMYT Partnership

Since 1983, when CIMMYT signed an MoU with the then Institute of Agricultural Research, the members of EARS have had close working relationships with CIMMYT in wheat and maize research projects that date back to 1980 with regards to the following activities: access to improved germplasm, variety development, variety release, popularization, crop management, socio-economic studies and assignment of resident scientists in Ethiopia.

EIAR's association with CIMMYT in maize research has enabled EIAR to earn a government subsidized status as an East Africa regional center of excellence for highland maize improvement. It also gave EIAR the opportunity to gain the confidence of the World Bank and obtain the recognition of our neighboring eastern African countries as being the Wheat Regional Center of Excellence under the East African Agricultural Productivity Program (EAAPP).

Germplasm exchange

Germplasm exchange is very much a part of the joint EIAR–CIMMYT maize and wheat improvement activities in Ethiopia (Table 3). Through access to CIMMYT's broad range of genetically improved maize and wheat germplasm with resistance to different pests, nutritional enhancement, stress tolerance, and heterotically differentiated germplasm groupings, the national wheat and maize research has been able to: 1) identify superior varieties/hybrids for release, 2) identify parental lines for targeted crossing, 3) develop new germplasm pools, and 4) enrich existing national gene pools and populations with new germplasm sources.

Varietal development

The vigorous EIAR–CIMMYT maize and wheat germplasm development and exchange program has resulted in the development of widely adapted hybrid and open-pollinated varieties of maize and pure line wheat varieties. The maize varieties grown in Ethiopia were mainly introduced from CIMMYT/IITA or were locally composed. All of the highland maize varieties released in the country were developed jointly by EIAR and CIMMYT scientists mainly with CIMMYT germplasm background. The collaboration was not limited only to knowledge but was also supported by routine lab activities. The nutritionally enhanced version of BH660 released in 2011 and the previously released quality protein maize (QPM) varieties involved CIMMYT headquarters with regard to nutritional quality analysis. The direct contribution of CIMMYT germplasm to those varieties released for the dry areas was also high and was estimated to be 78%. A number of varieties released for the mid-altitude sub-humid agro-ecological areas had CIMMYT genetic background—about 25% for the open-pollinated and 39% for the hybrids. Varieties that were released for the low-altitude sub-humid areas were directly selected from IITA germplasm introductions.

Table 3. Average number of CIMMYT trials introduced, number of entries and number of entries selected for further breeding each year.

Center	Number of trials introduced	Number of entries	Number of entries selected for further breeding
Melkasa	10	200–400	5–10
Ambo	2–4	60–100	1–3
Bako	7–10	200–300	3–5

Source: Personal communication with Dr. Mosisa, Dr. Gezahgn and Mr. Kassa

CIMMYT offered a significant germplasm and knowledge-base to develop competitive wheat varieties in the country. Thirty-seven of the forty-six bread wheat varieties released until 2009 found their origin from CIMMYT. Most of those varieties that originated from CIMMYT were popular and it is worth mentioning that the variety Kubsa (known as Attila in other countries) occupied up to 80% of the wheat producing area of Ethiopia until it was heavily attacked by yellow rust in 2010. Unlike the bread wheat, the proportion of CIMMYT genetic source for the durum wheat varieties released in the country was less. Based on the pedigree record of the 29 durum wheat varieties released until 2009, only 10 were of CIMMYT origin.

Crop management and socioeconomic research

Until the early 2000s, residents and scientists residing in other CIMMYT research stations in collaboration with local scientists undertook valuable agronomic and socioeconomics research. The output of the crop management and socioeconomics research has contributed to the productivity increase of wheat and maize at the farm level and improved social and economic benefit at society level. But in recent times the involvement of CIMMYT scientists in crop management research was reduced to nil. With the visit of the CIMMYT Director General to Ethiopia in 2009 and 2010, there are promises to regain the previous attention on crop management research.

Resident scientists

CIMMYT has appointed 11 resident scientists (Table 4) since 1987. Of these scientists, five were wheat breeders/pathologists or agronomists and two were maize specialists. Four were not attached to specific crops; socio-economists. In addition to their collaborative research work, the contributions of resident scientists have been in publications. They published scientific papers jointly with local scientists and were sources of information and helped to develop the interest and skill of scientific writing.

In general, these resident scientists were helpful in regard to:

- Liaison between the NARS and CIMMYT and other wheat and maize research organizations
- Helping to access project funding and in procurement of locally unavailable research consumables and supplies
- Undertaking joint research projects
- Coordinating and conducting local workshops and in-service training
- Jointly publishing research articles
- Getting involved in student advisory, examination, and research reviews
- Participating in demonstration, popularization and scaling out activities
- Developing research projects and looking for funding
- Providing information and advice on research and production issues

Financial support/small grants, USD, 2006–2010

Since 1980, CIMMYT's collaboration with Ethiopia in maize and wheat has been financed through several operational and institution-building grants. During the past five years, the small grants ranged from USD $43,988 to $186,266 (Table 5). As of 2010, under the coordination and management of CIMMYT, the ACIAR has contributed AUD $1,605,005 to implement a four year research project titled 'Sustainable intensification of maize-legume cropping systems for food security in eastern and southern Africa' (SIMLESA).

Training

Sustainable technology and knowledge generation in agricultural research, like other fields, requires dedicated and knowledgeable human resources. In the partnership this has been well addressed and has strengthened the skill of researchers and technicians through degree and short term hands-on training in different fields. The degree level study included four Ph.D. training (two full and two partially supported scholarships), three M.Sc. and two B.Sc. in maize. Most senior maize researchers/technicians attended CIMMYT short term training abroad. Apart from local breeding training in collaboration with CIMMYT, seed training and use of CIMMYT's field book software has been instrumental to the knowledge transfer and success of technology generation and dissemination. Farmer training through field days, field schools and demonstration plots has been offered. While training data is lacking for wheat, data for maize show that between 1968 and 2010, 45 trainees attended training and shared experience as visiting scientists at CIMMYT.

Recently, the SIMLESA program has supported the short term training of two junior researchers on maize breeding for drought tolerance, which was conducted in Zimbabwe during 15–30 August 2010. Local training on conservation agriculture (CA), cropping systems and agronomy was conducted during 17–22 October 2010 for 25 researchers, extension workers from Bureaus of Agriculture (BoAs), NGOs and private

Table 5. Research grants obtained through EIAR–CIMMYT collaborative research projects.

Type	Year	Amount (USD)
Small grant	2006	$43,988
Small grant	2007	$135,453
Small grant	2008	$186,266
Small grant	2009	$134,570
Small grant	2010	$139,444
Sustainable intensification of maize-legume cropping systems for food security in eastern and southern Africa (SIMELESA) Project grant	2010	USD $1,607,091/ AUD $1,605,005

Table 4. Name, profession and period of stay of CIMMYT scientists in Ethiopia.

No.	Name of scientist	Profession	Year
1	Maarten van Ginkel	Wheat Breeder/Pathologist, Ph.D.	August 1987–1989
2	Douglas Tanner	Wheat Agronomist, M.Sc.	August 1987–July 2004
3	Wilfred Mwangi	Agricultural Economist, Ph.D.	January 1988–July 1999
4	Osman Abdallah	Wheat Breeder/Pathologist, Ph.D.	January 1988–July 1993
5	Thomas Payne	Wheat Breeder/Pathologist, Ph.D.	September 1997–1999
6	Strafford Twumasi-Afriyie	Maize Breeder, Ph.D.	1999–Present
7	Dennis Friesen	Maize Agronomist, Ph.D.	August 2004–April 2010
8	Olaf Erenstein	Agricultural Economist, Ph.D.	August 2009–Present
9	Roberto La Rovere	Agricultural Economist, Ph.D.	August 2009–March 2011
10	Bekele G. Abeyo	Wheat Breeder/Pathologist, Ph.D.	April 2010–Present
11	Moti Jaleta	Agricultural Economist, Ph.D.	February 2011–Present

Source: CIMMYT–Ethiopia

investors. Moreover, two Ethiopians (from Bako and Melkasa Research Center) have been awarded a Ph.D. scholarship to attend their studies in Australia.

Vehicles and lab equipment

With the limited availability of supplies in the country and procedural requirements, our partnership with CIMMYT has improved procurement and availability of supplies and equipment. Through the small grant system, CIMMYT has purchased and donated pollination bags (Bako, Melkasa, Ambo, Hawassa and Haramaya University), lab equipment (Melkasa QPM Lab., light tables at Ambo, Bako and Melkasa, balances at Ambo and other centers), digital cameras and GPS (Ambo, Bako and others), equipment and installation cost to upgrade seed store (Bako, Ambo, Melkasa), irrigation equipment (Melkasa and Ambo), maize sheller and seed counter (Ambo) and vehicles (Bako, Ambo). CIMMYT has also donated farm implements, and supported the construction of warehouses and lath-houses as a package of the wheat research in Ethiopia. Three field cars which are now old were also donated by CIMMYT in the 1980s and 1990s (Bako, Wondogenet and Hawassa) for maize research. One second hand vehicle was donated in 2010 to strengthen the highland maize research. Two Toyota station wagons were also provided to the wheat research during the 1980s and 1990s.

Contribution of CIMMYT–EIAR Partnership on Production

While there has been quite substantial investment in maize and wheat research and extension, the gains in productivity and production have been better than any other crop. The development of superior maize and wheat varieties has lead to adoption of varieties and their production packages that revolutionize maize and wheat culture in the country. While the number of farmers that adopt the improved technologies is still limited, there is substantial difference between the farmers' practice and improved technologies. Maize is the most productive cereal in the country while wheat was the second until 2009. In 2009/10 wheat was surpassed by rice and sorghum and its position was shifted to fourth (CSA, 2010). The yield advantages of maize hybrids appear to be sufficiently large to attract the attention of farmers. Improved high yielding maize hybrids can express their full genetic potential only when offered optimum management resources.

Over the past 20 years, the area dedicated to wheat and maize cultivation in Ethiopia has expanded progressively (CSA, 2010). But the rate of expansion for wheat is higher than maize. Area under wheat cultivation has tripled while the area under maize has increased by about 50%. Although a substantial proportion of maize is still produced in the dry areas, both crops dominated the most productive agricultural lands in the country. In some of the drier areas, farmers tend to prefer maize cultivation over that of sorghum. Normally local production in maize is targeted to human consumption, local breweries, poultry feeds and in some years for export, while wheat is solely for human consumption.

According to the central statistics agency, between 1990 and 2009 the average national yield increased from 1.6 to 2.2 t ha^{-1} for maize and from 1.1 to 1.7 t ha^{-1} for wheat (Fig. 1). Nevertheless, had all farmers growing these two crops adopted the full range of technologies, tripling the current national productivity would have been achievable.

The increase in total production was attributed to both increases in area and productivity (CSA, 2010). Nevertheless, increases in productivity have contributed more to this increase in total production for maize than in wheat. For maize, the increase in total production during the last 20 years was 89%. This has been attributed to both area of production (39%) and productivity (38%). The detail of maize production and productivity in Ethiopia is discussed in Mosisa *et al.*, (these proceedings). In addition, the release of improved varieties and transfer of knowledge has contributed to the emergence and development of the seed sector and subsequent increase of certified seed production (Fig. 1).

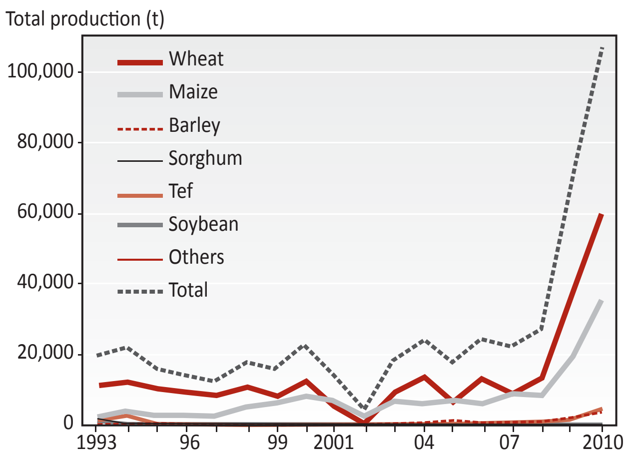

Figure 1. Certified seed production for major crops during 1993–2010.

Conclusion

In Ethiopia higher rates of growth in agricultural productivity are necessary to promote broad-based economic growth, reduce poverty, and conserve natural resources. In many developing countries technological change in agriculture has proved essential to reducing poverty, fostering development, and stimulating economic growth and this necessitates continuous application of science, technology, and information through national agricultural research and extension systems. The agricultural research undertaken for more than four decades in the country has been the basis for the recent improvement in agricultural production. But the achievements in developing momentous agricultural technologies are far from enough to bring the desired changes at the anticipated rate. Commonly, technological development processes are still complex, time consuming and not cost effective. Hence technological options are limited. The great advances in scientific methodologies and technologies which are necessary to address challenges require working together with a common vision and through pooling resources. Partners combine resources and share risks in pursuit of common objectives, while recognizing that each partner will also have additional objectives not shared by other members of the coalition. In this way they may achieve a solution that would not be possible for any individual partner. We agree that partnerships beneficially aligned to our research and development agenda allow for complementarities, comparative advantage and institutional synergy towards successful technology development and dissemination. Through strategic alliances in agricultural research and development, our recent experiences have offered a glimpse of hope and accelerated our efforts to emerge from the vicious cycle of poverty and hunger.

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Status and Future Direction of Maize Research and Production in Ethiopia

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Introduction

Ethiopia is endowed with huge potential for agricultural development and cereal crops like maize are widely cultivated across a range of environmental conditions. However, it has been one of the more food insecure countries of the world. Food insecurity in the country is mainly due to inadequate utilization of improved crop production and protection technologies by the predominantly small-scale farmers (CSA, 2010). Since 1952 maize research has been ongoing at different capacities to generate and recommend improved technologies for maize production. As a result, maize productivity and production has been increasing over the years. The progress made from the 1950s to 1990s has been documented in the proceedings of the First and Second National Maize Workshops of Ethiopia (Kebede *et al.,* 1993; Mosisa *et al.,* 2002). In the 2000s, efforts have also been made by different stakeholders to enhance maize research, and thus increase maize productivity and production.

In this paper, highlights of maize research activities and the latest trends in maize productivity and production (in the 2000s) in Ethiopia are discussed. Future directions for maize research and production are also suggested.

Maize Research

Research activities in the 2000s

In the 2000s, the previously established and used agro-ecology based research in maize (Kebede *et al.,* 1993; Mosisa *et al.,* 2002) has been maintained. This approach has resulted in the release of improved maize technologies for each maize agro-ecology. However, environmental variability (both natural and due to management) that prevails within each maize agro-ecology needs continuous research to develop high yielding varieties adapted to these different environmental conditions. For example, small-scale farmers, who have different levels of maize field management skills and capacities for the purchase and utilization of inputs, mainly produce the largest proportion of maize grain in Ethiopia (CSA, 2010). This requires that the released/recommended maize varieties should be exposed to different management levels in the farmers' fields.

According to Lynch (1998) there are three approaches of germplasm improvement for grain yield in the farmers' field: (1) improving yield response to high levels of input, (2) improving yield under low input availability, and (3) improving yield under both low and high input availability. Improving crop yield only under high levels of input may result in varieties unsuitable for low input conditions which occur frequently in resource poor farming conditions. Similarly, improving crop yield when only under low levels of input may result in non-responsive crop types. Generally, the National Maize Research Project follows the third option for maize improvement (Bänziger *et al.,* 2000; Mosisa *et al.,* 2007). It undertakes maize research country-wide in four major maize agro-ecologies each having its own limitations and potentials.

The mid-altitude and low-altitude sub-humid maize research program evaluates maize varieties across locations in their respective agro-ecologies under different management levels recommended for maize at each research center in order to identify stable varieties (Table 1). Selected varieties are also evaluated and assessed by the end-users in different farmers' fields under recommended management practices before their release. In addition, maize hybrids and open-pollinated varieties (OPVs) are evaluated under both high (100 kg ha^{-1} N/100 kg ha^{-1} P_2O_5) and low (22 kg ha^{-1} N/46 kg ha^{-1} P_2O_5) levels of input within the national maize research project based at Bako Agricultural Research Center (ARC). Similar approaches have been followed by the highland maize breeding program at Ambo ARC, except that they have not yet started evaluation of varieties under low input (low soil fertility) conditions on the station.

The low-moisture stress maize research program tests its germplasm (inbred lines, OPVs, hybrids) under both well-watered and low-moisture stress conditions using controlled sprinkler and furrow irrigation in the dry season at Melkasa ARC. It also evaluates promising genotypes under rain-fed conditions across locations at different research centers situated within the agro-ecology (Table 1).

During the early stages of maize breeding in Ethiopia, the main focus of the breeders was development of OPVs (Benti *et al.,* 1993; Kebede *et al.,* 1993). This was mainly due to the assumption that small-scale farmers did not have the skill required to manage hybrid maize (Takele, 2002), unavailability of improved germplasm locally for hybrid development, lack of experience in hybrid development and absence of seed producers. However, it seems that the high yield realized on the state farms with hybrids imported from Kenya, Zimbabwe and Malawi in the early 1980s together with high yield potential recorded from some experimental hybrids in the research centers convinced the breeders to go for wide development and testing of maize hybrids locally. This led to a shift in the breeding strategy from development of only OPVs to development of both hybrids and OPVs in the early 1980s, particularly for the potential maize growing areas (Benti *et al.,* 1993). In the 2000s, this approach has been maintained and both hybrids (three way crosses, top crosses, single crosses) and OPVs (both synthetics and composites) of different maturity groups (intermediate to late maturity, 130/140–180 days) have been the main focus of the breeders, particularly for the mid-altitude and highland sub-humid maize growing areas with 4–6 months of rainy season.

In low moisture stress areas of Ethiopia, the main focus was development and release of drought escape and/or tolerant OPVs of different maturity groups (extra early, 90 days, to intermediate maturity, 120–130 days). However, there are on-going research activities which began in the late 2000s at Melkasa ARC for the development of early to intermediate maturing hybrids (non-conventional and conventional hybrids) for rain-fed and irrigated agriculture in order to exploit heterosis in the low moisture stress areas of Ethiopia. Similarly, development of maize streak virus resistant OPVs was the main focus for the Gambela plain lowland sub-humid; but the development of agriculture and increase of commercial farms in the area forced the maize breeders to test hybrids in the area in the late 2000s, and this may lead to the release of commercial hybrids for the region in the near future.

In recent years, grain production under residual moisture on the bottomlands and under irrigated conditions is increasing (CSA, 2010). During the 2000s efforts were made to evaluate released and pipeline maize varieties under residual moisture and irrigated conditions and to recommend varieties for commercial production.

Table 1. Major maize testing centers located in different maize agro-ecologies of Ethiopia.

Agro-ecology	Center	Altitude (masl)	Annual rainfall (mm)	Temperature (°C) Max.	Temperature (°C) Min.	Relative humidity (%)	Latitude (°North)	Longitude (°East)
Mid-altitude sub-humid	Bako	1,650	1,211	27.9	12.9	56.3	9.12	37.08
	Hawassa	1,708	945	26.7	12.3	55.0	7.03	38.28
	Asosa	1,560	1,247	27.8	14.4	–	10.07	34.52
	Finotasalem	1,853	1,125	–	11.2	–	10.40	37.16
	Jimma	1,725	1,448	27.2	11.4	60.0	7.67	36.83
	Pawe	1,050	1,585	32.1	16.4	–	11.15	36.05
	Tepi	1,540	1,598	29.3	16.0	–	6.98	35.25
	Areka	1,750	1,401	25.8	12.5	–	7.07	37.68
	Haramaya	2,050	820	23.4	8.9	–	8.37	42.02
	Arsi-negele	1,940	900	–	–	–	7.19	38.39
Highland sub-humid	Ambo	2,225	1,115	25.4	11.7	–	8.57	38.07
	Adet	2,203	1,118	25.7	8.5	–	11.17	37.29
	Holota	2,400	1,065	22.1	6.4	60.0	9.00	34.48
	Kulumsa	2,180	824	23.0	10.0	–	8.13	39.13
	Haramaya	2,050	820	23.4	8.9	–	8.37	42.02
	Arsi-negele	1,940	900	–	–	–	7.19	38.39
	Gonder	1,967	1,183	26.9	12.9	–	12.53	37.42
Lowland sub-humid	Gambela	480	1,070	34.8	20.2	–	8.23	34.57
Low moisture areas	Melkasa	1,540	734	28.4	14.1	54.5	8.40	39.32
	Alamata	1,580	709	27.3	13.7	–	12.52	39.68
	Mekele	2,070	620	23.1	11.7	–	13.5	39.48
	Humera	550	572	37.9	20.2	–	14.28	36.57
	Jijiga	1,644	719	27.4	11.3	–	9.21	42.47
	Miesso	1,327	801	30.3	14.6	–	9.13	40.45
	Sirinka	1,900	1,019	26.2	13.6	–	11.75	39.60
	Werer	800	566	34.2	18.3	–	9.42	40.33
	Yabello	1,740	650	25.5	13.0	–	4.87	38.10
	Ziway	1,640	760	26.7	13.7	–	8.00	38.75

In addition to abiotic stresses, various biotic stresses limit maize production and productivity in different maize growing agro-ecologies of the country. Currently, grey leaf spot (GLS), *turcicum* leaf blight (TLB), common leaf rust (CLR) and *phaeosphaeria* leaf spot (PLS), stalk borers, termites and maize weevils are the major biotic constraints limiting maize production and productivity in different areas of the mid-altitude sub-humid maize agro-ecology. The importance of PLS has increased in the past decade. Screening of maize genotypes against major foliar diseases (GLS, TLB, CLR and PLS) and maize weevil under artificial inoculation/infestation and/or at hot spot areas has been ongoing at Bako. The results are encouraging. However, there is a need to build well equipped laboratories along with qualified personnel for better progress in the future. Screening against biotic stresses has also been in progress in other maize centers/maize agro-ecologies using hot spot areas for the biotic stresses in specific areas. For instance, screening of CIMMYT imazapyr resistant maize (IR-maize) materials using striga infected and striga free plots began in the early 2000s and it is in progress at Pawe. Screening of striga resistant International Institute of Tropical Agriculture (IITA) materials against striga was also initiated at Pawe in the late 2000s.

Breeding for quality traits has been enhanced at different maize centers situated in different agro-ecologies during the 2000s. The quality traits include: protein quality, pro-vitamin A (yellow) and stover/feed quality traits. Future progress in this area may depend on local capacity building (laboratory facilities and trained man power). Intensive evaluation of introduced popcorn materials across locations was also launched in the late 2000s.

Furthermore, the National Maize Research Project has been evaluating hybrids of the multinational (Pioneer Hi-Bred Seed Company PLC and Seed-CO International PLC) and local (Ethiopian Seed Enterprise) seed companies, upon their request, and has recommended adapted hybrids with good yield potential for commercial production in Ethiopia. Hybrids which were found to be inferior in performance to the local checks; for example, hybrids of Red-Speckled (ZAMA) Seed Company, were rejected by the National Maize Research Project.

Overall, in the past decade 25 maize varieties (16 hybrids and 9 OPVs) were released for commercial production in different maize agro-ecologies of Ethiopia by the National Maize Research Project and seed companies. The seed companies' hybrids represent 28% of the releases. In addition, of the four varieties (3 hybrids and 1 OPV) released for commercial production in Ethiopia in 2011, one hybrid variety belonged to a private seed company. The public and private small-scale seed companies produce and sell seeds of the hybrids developed and released by the National Maize Research Project.

Maize research in other disciplines (agronomy, protection (both entomology and pathology), mechanization, utilization and socio-economics) has also been conducted in different maize centers situated in different maize agro-ecologies. Fertilizer type, rate, time and method of application, cultural practices research and cropping system research were the focus of agronomic research, particularly in the highlands where maize is newly expanding. Agronomic research for irrigated maize has been done in the low moisture stress areas of Ethiopia. Research on storage structures and improving farm implements used by maize farmers in maize farming has also been in progress by the agricultural mechanization research centers, both federal and regional research centers. Moreover, Melkasa ARC's Food and Post-Harvest Research Section and the Ethiopian Health and Nutrition Research Institute have conducted research on utilization of maize grain for different food items.

Research coordination and partnership with other organizations

The history of maize research coordination in Ethiopia was presented in detail by Kebede *et al.* (1993) and Mosisa *et al.* (2002). Therefore, in this section only research coordination and partnership in the 2000s is presented.

After the business process re-engineering (BPR) implementation in 2008, the Ethiopian Institute of Agricultural Research (EIAR) re-organized its research programs under research processes; namely, crop research, animal research, water and soil management research, forestry research and mechanization research. Within the crop research process, different case teams (formally called programs) were organized. One of these case teams is a cereal case team, which encompasses maize, wheat, barley, *tef*, rice, sorghum and millet commodity projects.

Under the maize commodity project, four maize research projects were developed; namely, mid-altitude sub-humid, highland sub-humid, low moisture stress and lowland sub-humid. The low moisture stress maize research project has been coordinated from Melkasa ARC while the highland maize research project has been coordinated from Ambo ARC. The mid-altitude sub-humid and low-altitude sub-humid maize research projects have been coordinated from the National Maize Research Project based at Bako Agricultural Research Center (BARC). The main coordinating centers are mainly responsible for development and organizing maize germplasm to be tested at different sites managed by federal and regional research centers and higher learning institutions, in their respective maize agro-ecologies. However, each maize research center has the responsibility to decide and coordinate research activities targeting specific problems in its area. The Bako National Maize Research Project continued to be the national coordinating center - center of excellence, for national maize research in Ethiopia as a whole.

At the inception of maize research in Ethiopia, the national maize research program of Ethiopia collaborated with national and international (CIMMYT, IITA) research organizations in evaluation of maize variety trials (Benti *et al.,* 1993; Mosisa *et al.*, 2002). The partnership with the Consultative Group on International Agriculture Research centers in germplasm exchange and local maize research capacity building has also been enhanced during the 2000s. For instance, CIMMYT allocated small grants to support maize research in Ethiopia. The small grant funds have been used to fill the gaps at different research centers which were not covered by government budgets, after approval by EIAR management. Short term and long term training (BSc, MSc, PhD level), technical advice, support in establishing/upgrading irrigation facilities, seed storage and laboratories, purchase and donation of field and office equipment/consumables and vehicles were among the support rendered by CIMMYT. In addition, CIMMYT-Ethiopia assisted the national maize research of Ethiopia in exploration and introduction of improved germplasm from different regions of the world. Recently, IITA has also started to offer short and long term training to researchers working in the National Maize Research Project. Sasakawa Global 2000 (SG2000) supported the program by providing a station wagon with its full running cost to the coordinating center (Bako). Together with CIMMYT, SG2000 has also contributed financially and technically to the upgrading of the Melkasa quality protein maize laboratory.

Research planning and implementation

The research planning and implementation strategy in the 1990s is documented in Mosisa *et al.* (2002). Before the re-engineering of EIAR research program in 2008, maize research activities of different disciplines were proposed by researchers in different disciplines in a piecemeal approach. Each research activity proposal was reviewed at division, center, Zonal Research and Extension Liaison Committee meetings and finally at a National Maize Research Project review meeting. The approved activities were also presented at the EIAR annual review meeting. Annual reviews at each level used to be held every year to review proposals for new research activities and summarize results for on-going, discontinued, suspended and completed activities. At each stage of review a new proposal could be approved/rejected/suspended based on relevance of the project and resource availability. Once the research activities were approved, they were cataloged in a research directory under the National Maize Research Project. Then each activity was implemented from 1 to 3 years at one location or across locations, according to the plan in the proposal.

After the re-engineering of EIAR's research program in 2008, projects are proposed once for 3 years in a holistic manner from technology development to dissemination. Maize research projects are initiated based on maize agro-ecologies (mid-altitude sub-humid, highland sub-humid, low-altitude sub-humid and low moisture stress areas). All the research activities in each project are presented and approved by representatives from maize centers representing different maize agro-ecologies. The projects are compiled under the National Maize Commodity Research Project and submitted to the cereal case team leader which is under the crop research process according to the new EIAR's re-engineering set up. The national maize commodity research projects are peer reviewed by an external body and the cereal case team leader presents the proposals at the crop process review with other cereal crop projects for approval. Each activity is implemented at one location or across locations for 1–3 years, according to the research plan in the proposal. In 2010, slight modifications were made in the review process. Accordingly, maize projects were reviewed at center, Zonal Research, Extension and Farmer Linkage Advisory Council meetings and national cereal case team review meetings. There is a possibility of executing new activities under each project, if there is a need, after approval at each of the review stages.

Monitoring and evaluation

Research activities were monitored and evaluated using field visits, quarterly and annual reports. Each center has a monitoring and evaluation committee, which visits research fields at each center and prepares monitoring and evaluation reports for the center research activities. The National Maize Commodity Research Project monitoring and evaluation committee at the national maize research coordinating center (Bako) has been making field visits to most maize centers in the country to assess the status of each activity under field conditions. In addition, the committee has been receiving the final monitoring and evaluation report from each center. Then it prepares the final monitoring and evaluation report for the national maize commodity research and submits it to the cereal case team coordinator, to be presented at Crop Research Process monitoring and evaluation review meetings.

Maize Productivity and Production Trends in the 2000s

Cereals are the major crops produced in the country and they constitute the largest share of domestic food production. In 2010/11 main cropping season, cereals were cultivated on 9.9 million hectares producing 17.2 million t of food grains (CSA, 2010). This represented 82.3% and 87.7% of the total area and production of food grains in the country, respectively. Among cereals, maize ranked second to *tef* in area coverage (21.7% for maize and 27.4% for *tef*), and first in total production (28.5% for maize and 19.9% for *tef*) and productivity (Table 2). The per capita consumption of maize in Ethiopia is about 60 kg per annum; however, the level of consumption varies from place to place. In major maize producing areas, maize is a staple food, and in other areas it is used in mixtures with other food grains.

According to CSA reports (2010) maize area and production have increased in the 2000s (Table 3). The average maize area in the 1990s was 1.2 million hectares while it was 1.6 million hectares in the 2000s; an increase of 31%. Similarly, maize production has increased over the years. The average total production per year was 2.0 million t in the 1990s, while it was 3.3 million t in the 2000s (Table 3); an increase of 66%.

Division

Although the current average national maize yield of Ethiopia, 2.5 t ha^{-1}, is better than the national yield of many African countries, it is still low compared to that of the world and developed countries' average maize productivities (Table 4). Even the average maize yields obtained through the government extension program, 5.0 t ha^{-1}, (Ibrahim and Temene, 2002) and on-station (8–11 t ha^{-1}) in the high rainfall and irrigated areas of Ethiopia indicate that the national average maize yield is below what can be achieved with the currently available maize technologies in the country. However, maize productivity varied from place to place mainly depending on soil fertility status, availability of moisture during the growing season and utilization of the recommended maize production and protection technologies. For instance, in 2008, average maize grain yield in the Amhara region varied from 1.3 t ha^{-1} (Waghemra zone) to 2.8 t ha^{-1} (East Gojam zone). In the same year, the average maize grain yield ranged from 1.8 t ha^{-1} (West Hararge zone) to 3.1 t ha^{-1} (Horo Guduru Wellega zone) in Oromia. It also ranged from 1.4 t ha^{-1} (Amaro special *woreda*) to 2.1 t ha^{-1} (Sidama zone) in the Southern Nation and Nationalities People Region (CSA, 2010). Similarly, the average yield varied from place to place in the other regions. Generally, maize productivity in Ethiopia has increased over the years. The average national grain yield in the 1990s was 1.6 t ha^{-1}, while it was 2.1 t ha^{-1} in the 2000s, indicating that the national average maize productivity has increased by 30% in the 2000s as compared to

Table 2. Cereal cropping area, production and productivity in Ethiopia for the main-season, 2010/11 .

Crop	Area ('000 ha)	Total production ('000 t)	Yield (t ha^{-1})
Cereals	9,905	17,238	
Tef	2,723	3,434	1.3
Barley	1,045	1,588	1.5
Wheat	1,608	2,751	1.7
Maize	1,963	4,986	2.5
Sorghum	1,903	3,768	2.0
Finger millet	422	679	1.6
Oats	25	30	1.2
Rice	48†	103†	2.2†

Source: CSA, 2010. †2009 data.

Table 3. Maize area, production and productivity trends in Ethiopia and maize average grain price at Bako Agricultural Research Center, (1990–2010).

Year	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})	Price (Birr 100 kg^{-1})
1990	1,277	2,056	1.6	33
1991	908	1,159	1.3	59
1992	751	1,234	1.6	88
1993	808	1,392	1.7	53
1994	902	1,113	1.2	109
1995	1,104	1,673	1.5	96
1996	1,851	3,105	1.7	45
1997	1,688	2,928	1.7	66
1998	1,448	2,344	1.6	84
1999	1,303	2,417	1.9	108
2000	1,407	2,525	1.8	83
2001	1,323	2,800	2.1	33
2002	1,702	3,086	2.2	49
2003	1,336	2,543	1.9	115
2004	1,399	2,407	1.7	99
2005	1,526	3,337	2.2	117
2006	1,793	4,030	2.2	122
2007	1,767	3,750	2.1	155
2008	1,768	3,933	2.2	302
2009	1,772	3,897	2.2	270
2010	1,963	4,986	2.5	186

Source: CSA (2010)

the 1990s. The national average yield for the five years (1990–1994), before the intervention of SG2000 and government extension programs, was 1.5 t ha^{-1} while the national average yield for the past five years (2006–2010) was 2.2 t ha^{-1}, a 49% increase.

The increase in maize productivity and production in the past decade is the result of awareness created by government extension support, availability of improved maize varieties and other technologies, relatively attractive maize grain prices in most of the years (Table 3), and relatively improved infrastructure and market access. Thus, it seems that sustainable increments in maize productivity and production in Ethiopia depends on availability of improved maize technologies (improved seed and other inputs), availability of moisture during the growing season, soil conservation and fair grain prices.

Challenges and Future Directions

The sustainable maize research in Ethiopia is mainly due to the continued government budget allocation (2.9 million Birr, capital budget per year from 2009 to 2010) for maize research and strong support from international organizations, particularly CIMMYT. This is expected to continue in the future for strong maize research in Ethiopia which is indispensable for increased maize productivity and production. Moreover, continued strong maize research relies on the presence of educated researchers with adequate knowledge and skill. Thus, the efforts of building the capacities of the research staff through short and long term training should be strengthened. Reasonable and attractive salaries are also important to reduce/prevent the high turnover of researchers and other supporting staff.

Table 4. Maize area, production and productivity in different regions of the world in 2008.

Country/region	Area ('000 ha)	Total production ('000 t)	Yield (t ha^{-1})
China	29,883	166,035	5.6
Ethiopia	1,767	3,776	2.1†
South Africa	2,799	11,597	4.1
United States of America	31,826	307,384	9.7
World	161,017	822,713	5.1
Africa	29,152	53,201	1.8
Eastern Africa	13,551	17,624	1.3
Middle Africa	3,476	3,037	0.9
Northern Africa	1,072	6,731	6.3
Southern Africa	3,080	11,780	3.8
Western Africa	7,973	14,029	1.8

Source: FAO, 2008. †CSA data shows 2.2 t ha^{-1} for the same year, see Table 3.

Maize research in different agro-ecologies of Ethiopia has continued sustainably in the 2000s. Efforts were made to start new maize research activities and enhance the existing ones. Quality protein maize research, yellow maize research, characterizing and screening of maize genotypes for stover/feed quality traits, evaluation of popcorn for local adaptation, screening of maize genotypes for biotic and abiotic stresses under managed stresses could be listed as good examples of new endeavors during the past decade. Despite all the efforts and progress made so far in development and dissemination of maize technologies for different agro-ecologies, the biotic and abiotic constraints still remain the major limiting factors for increasing maize productivity and production. Thus, development of improved maize technologies should be a continuous process for tackling the existing problems and emerging challenges (new pests, and climate change), and to meet the changing farming system needs. In addition, maize research in Ethiopia should be enhanced by molecular biology techniques for better progress in the future. Therefore, with increasing capacity building (both human and infrastructure) some maize breeding activities in Ethiopia should focus on specific problems in different areas by combining conventional and molecular breeding.

Maize production in Ethiopia has increased in the past decade because of both an increase in maize area and productivity. Maize area is expected to increase in the future mainly due to expansion of maize production in new areas and availability of new maize varieties for a wide range of environmental conditions. Expansion of maize production in new areas as an alternative crop should be encouraged. However, in areas where maize is the dominant crop, an increase in maize production should come mainly from increased maize productivity instead of an increase in maize area. In these areas maize is mainly mono-cropped but farmers fail to attain the yield potential of the improved varieties due to the decline in soil fertility. Unless mono-cropping is replaced by maize–pulse rotation and/or the soil is conserved and managed well, maize production in these areas will be endangered.

In general, the increase in the average national maize productivity in the past decade is encouraging. This increment is achieved under a condition where only approximately 20% of maize area (main-season) in the country is sown to improved seed and on average only approximately 22 kg ha^{-1} of mineral nutrients are applied. This indicates that if improved maize technologies (improved varieties, other inputs and management practices) are used by most or all of the maize producing farmers in the country and the natural resource is conserved, doubling of the current national average maize yield, 2.3 t ha^{-1}, could be achieved, as envisaged by the Growth and Transformation Plan of the country. Besides, sustainable maize productivity increments in the future will largely depend on continuous and strong maize research supported by modern maize breeding techniques.

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Genetic Improvement of Maize for Mid-Altitude and Lowland Sub-Humid Agro-Ecologies of Ethiopia

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Introduction

Maize is one of the most important field crops in terms of area coverage, production, and economic importance in Ethiopia. It grows from sea level to over 2,600 masl., from moisture deficit semi-arid lowlands, mid-altitude and highlands to moisture surplus areas in the humid lowlands, mid-altitudes and highlands. Of these ecologies, the mid- and low-altitude sub-humid maize agro-ecologies are well known for maize cultivation in Ethiopia. The mid-altitude is mainly located in western, southern, eastern and central regions while the low altitude is found in the south western parts of the country. The weather conditions characterized by warm temperatures and sufficient volumes of rainfall coupled with the relatively fertile soils of these regions creates favorable conditions for maize cultivation.

Despite such circumstances, the potential maize productivity in the low- and mid-altitude sub-humid areas is not yet exploited and is unable to play a role in ensuring food security for the country. The estimated average yields of maize in the mid- and low-altitude areas are about 2.5 t ha^{-1} and 2.0 t ha^{-1}, respectively (CSA, 2010). This is far below the world average (5.1 t ha^{-1}) (FAO, 2008). One of the major constraints affecting maize production and productivity in these agro-ecologies is inadequacy of broadly adapted, high yielding, disease and insect resistant varieties. In addition, the weather conditions varying between seasons and locations within these agro-ecologies is another limitation. Such factors associated with the low level of crop management practices, the increasingly dwindling soil fertility situation, incidence of erratic diseases and insect pests, and escalation of climatic changes are growing concerns for maize production in Ethiopia.

Over the years substantial efforts have been made in our breeding program to improve the genetic potential of maize germplasm. Consequently, commendable success has been recorded focusing on the development and identification of superior hybrids and open-pollinated varieties (OPVs). Also, a number of useful breeding materials and genetic information have been generated and made available for breeding purposes. Achievements made before 2001 were well presented and documented (Benti *et al.,* 1993; Mosisa *et al.,* 2002). The present paper highlights an overview of progress made and achievements recorded during the past ten years and puts forward future directions for maize research in the mid- and low-altitude sub-humid areas of Ethiopia.

Development of Inbred Lines

The development of inbred lines and identification of their best hybrid combinations are the major focus of maize improvement activities in our research program. Large numbers of inbred lines are regularly generated from different sources of germplasm such as local populations, introduced populations, recycled inbred lines and back cross populations, and F_2 populations of locally adapted hybrids. About 2,000–3,000 inbred lines of various developmental stages are evaluated every year. The pedigree method of inbred line development is most commonly used while practicing visual selection at each generation for important characteristics. Vigor, adaptation, disease and insect tolerance, lodging tolerance, maturity, plant and ear heights, plant and ear aspects, and anthesis silking interval (ASI), pollen shedding capacity and silk extrusion are basically considered during selection.

In order to assess combining ability effects of the inbred lines, early testing is commonly practiced in our breeding program. Inbred lines selected at S_3 stage are test/top crossed with testers and their cross performances are evaluated in replicated trials at 2–3 locations. On the basis of their *per se* and cross performances, superior inbred lines are identified for further selfing in subsequent generations until homozygosity and uniformity is attained. Promising inbred lines generated from different sources of germplasm locally are presented in Table 1. Most of these inbred lines are beyond four generations of inbreeding and have manifested high levels of combining ability effects, good performances, and high degrees of resistance to economically important maize diseases, and some of them are tolerant to maize weevils.

Introduction and selection of useful inbred lines from exotic sources is also a routine undertaking. The breeding program introduces fixed or intermediate (semi-processed) inbred lines from international research institutes such as CIMMYT and International Institute of Tropical Agriculture (IITA). These inbred lines, prior to their evaluation for hybrid combinations, are screened and evaluated for their adaptation and disease reactions under local conditions. A number of white elite inbred lines (CML464, CML444, CML442, SC (PHAM)-3/(CML205/SC//CML202)-X)-4-B-B-B and DRBF2-60-1-2)-B-1-B-B-B) have been identified over the last ten years from exotic sources. The yellow kernel inbred lines are presented in a separate paper.

Development of Hybrid Maize Varieties

Since the inception of maize hybrid technology in the early 1900s in North America, a number of success stories have been recorded in the exploitation of heterosis for yield increments (Hallaur, 1988). This led to a widespread promotion and popularization of the technology, where hybrid maize varieties have been largely believed to improve productivity and help ensure a reliable and sustainable supply of food and feed worldwide (Hallaur, 1988).

Table 1. Locally developed prospective mid-altitude maize inbred lines.

No.	Pedigree	Heterotic group
1	(DRBF2-60-1-2)-B-1-B-B-BXF7215)1-1-3	AB
2	(LZ956343/LZ956003)-B-1-1-2-B-BX124-b(113)-3-1-1	AB
3	30H83-5-1-1-1-1-1	B
4	30H83-5-1-2-1-1-1	B
5	30H83-5-1-3-2-1-1	–
6	30H83-56-1-1-1-1	AB
7	30H83-56-1-1-2-1	AB
8	30H83-7-1-2-1	AB
9	30H83-7-1-3-1-1-1	–
10	30H83-7-1-5-1-1-1	B
11	30H83-7-3-4-1-1	B
12	BH660F2-10-2-1-2-1	B
13	DE-78-Z-126-3-2-2-1-1g	B
14	DE-78-Z-126-3-2-2-1-1p	B
15	Gibe1-158-1-1-1-1	B
16	Gibe1-178-2-1-1-1	B
17	Gibe1-20-2-2-1-1	A
18	Gibe1-91-1-1-1-1	A
19	IL’00E -47-2-3-1-1	A
20	IL’00E-1-12-4-1-1	A
21	IL’00E-1-9-1-1-1-1-1	B
22	IL’00E-5-5-3-1-1	AB
23	Kuleni 320-2-3-1-1-1	A
24	Kuleni 353-1-1-1-2	B
25	POOL9A-105-1-1-1-1-1	A
26	POOL9A-5-1-1-2-1	B
27	SZSYNA99F2-7-2-1-1	A
28	X1264DW-1-2-1-1-1	AB
29	IL00’E-1-10-4-1-1	A

History of hybrids maize research in Ethiopia is of recent undertaking. Beginning from the early 1950s to 1980s research emphasis had been on evaluation and selection of improved OPVs and hybrids of East African origin to recommend suitable varieties for high potential areas. At the same time the breeders were developing OPVs, locally. Later on, the focus shifted to develop hybrids along with equal footings with OPVs under local conditions.

In 1988 the first top cross maize hybrid was locally released for commercial production for the mid-altitude sub-humid agro-ecology (Benti *et al.,* 1993). With growing interest to develop more advanced high yielding and broadly adapted maize varieties, substantial efforts have been expended, and consequently different types of hybrids and OPVs have been identified and made available for commercial production (Benti *et al.,* 1993; Mosisa *et al.,* 2002). In a similar manner, the research program, beginning from the early years of the past decade, has made significant efforts to identify high yielding varieties, and thus has given more attention to hybrids than OPVs. The breeding program in this regard allocated much of its time and resources to hybrid development which accounts for about 80% of the overall activities. The objective has been mainly to enhance production and productivity of maize at a national level through the use of hybrid technology. Another important step that received research attention during these times has been to give more emphasis on development of medium maturing hybrids, rather than late maturing ones, largely to cope with the prevailing climatic challenges facing maize production. Furthermore, high priority has been given to develop three-way cross hybrids rather than single cross hybrids chiefly to address the needs of local seed producers. This is mainly because of the fact that under the existing management practice, seed yield obtained from an inbred parent is low and no premium price is paid for the production of single cross hybrid seed to attract local companies. Nevertheless, such a breeding approach is less flexible due to the significance of single cross hybrids against three-way cross hybrids. Good effort has been undertaken to develop single crosses and some of them have been released for commercial production.

Over the past ten years, six hybrid maize varieties, BH670, BHQP542, BH541, BH544, BH543, BHQPY545 and BH661, were released for commercial production in the mid-altitude sub-humid maize agro-ecologies. Five of them are medium maturing, of which two hybrids are quality protein maize (QPM) varieties. Only BH670 and BH661 are late in maturity. Currently, most of these hybrids are under commercial cultivation along with some other varieties (Table 2). BH544 was observed to be severely affected by gray leaf spot and *turcicum* leaf blight diseases and the female parent of BH541 became susceptible to ear rot disease and thus both varieties were banned from commercial production.

Development and release of a choice of maize varieties has been an eminent phenomenon in our breeding program mainly to accommodate a range of weather conditions, varying disease prevalence, and volume and distribution of rainfall. The strategy in this case is to come up with more advanced varieties than the existing ones in many aspects. Consequently, the breeding program has identified a number of promising conventional and non-conventional hybrids over the past decade (Tables 3, 4, 5 and 6).

Table 2. Maize varieties available for commercial production in the mid- and low-altitude sub-humid ecologies.

Variety		Source/ Origin	Year of release	Altitude (masl)	Rain fall (mm)	Days to maturity	Seed color	Yield (t ha^{-1}) Research station	Yield (t ha^{-1}) Farmer's field
Hybrids	BH660	EIAR	1993	1,600–2,200	1,000–1,500	160	White	9.0–12.0	6.0–8.0
	BH540	EIAR	1995	1,000–2,000	1,000–1,200	145	-	8.0–9.0	5.0–6.5
	BH140	EIAR	1988	1,000–1,700	1,000–1,200	145	-	7.5–8.5	4.7–6.0
	BH543	EIAR/CIMMYT	2005	1,000–2,000	1,000–1,200	148	-	8.5–11.0	5.5–6.5
	BHQPY545†	CIMMYT	2008	1,000–1,800	1,000–1,200	144	Yellow	8.0–9.5	5.5–6.5
	BH670	EIAR	2002	1,700–2,400	1,000–1,500	165	White	9.0–12.0	6.0–8.0
	BHQP542†	CIMMYT	2002	1000–1,800	1000–1200	145	White	7.0–8.5	5.0–6.0
	BH661	EIAR/ CIMMYT	2011	1,600–2,200	1,000–1,500	160	White	9.5–12.0	6.5–8.5
OPVs	Kuleni	EIAR/CIMMYT	1995	1,700–2,200	1,000–1,200	150	-	6.0–7.0	4.0–4.5
	Gibe1	EIAR	2000	1,000–1,700	1,000–1,200	145	-	6.0–7.0	4.0–4.5
	Gutto	CIMMYT	1988	1,000–1,700	800–1,200	126	-	3.0–5.0	2.5–3.0
	Morka	EIAR	2008	1,600–1,800	1,200–2,000	180	-	7.0–9.0	4.0–6.0
	Rare1	HU	1997	1,600–2,200	900–1,200	163	-	6.0–7.0	4.0–4.5
	Abo-Bako Gambela	IITA/CIMMYT	1986	300–1,000	900–1,200	112	White	5.0–6.0	3.5–4.5
	Comp1	IITA/CIMMYT	2002	300–1,000	900–1,200	116	-	6.0–7.0	4.0–5.0
	Gibe2	CIMMYT	2011	300–1,000	900–1,200	116	-	6.5–7.0	4.5–5.0

Source: Progress Reports of the National Maize Research Project, 1988–2010. †Quality protein maize, EIAR = Ethiopian Institute of Agricultural Research, HU = Haramaya University, IITA = International Institute of Tropical Agriculture, OPVs = open-pollinated varieties.

Table 3. Mean yield of selected medium maturing top cross hybrids evaluated across years and locations in different trials.

Pedigree	Mean yield (t ha^{-1})	Percentage of check BH540	Percentage of check BH543	Source of parents
SC gp. Pool /IL'00E-1-12-4-1-1	11.7	121	94	EIAR
SC gr. Pool/CML 395 /	12.2	127	98	EIAR/CIMMYT
AMS syn./IL'00E-1-12-4-1-1	12.3	127	98	EIAR
SC gr. Pool /CML312	10.9	112	87	EIAR/CIMMYT
SC gr. Pool /CML442	11.9	123	95	EIAR/CIMMYT
AMS syn./Gibe1-158-1-1-1-1	11.3	124	120	EIAR
GutoLMS5/30H83-7-3-4-1-1	10.6	116	113	EIAR
AMS.Syn./CML464	10.2	105	82	EIAR/CIMMYT

Source: National Maize Research Project Progress Reports (2001–2010). EIAR = Ethiopian Institute of Agricultural Research.

Table 4. Mean yield of promising late maturing three-way cross hybrids tested and identified across years and locations in different trials.

Pedigree	Mean yield (t ha^{-1})	Percentage of check		Source of parents
		BH660	BH670	
CML395/CML202//142-1-e	11.2	109	107	EIAR/CIMMYT
Gibe1-20-2-2-1/F7215//144-7-b	10.0	123	109	EIAR
IL'00E -47-2-3-1-1/CML197//142-1-e	10.8	120	103	EIAR/CIMMYT
CML383/F7215//142-1-e	10.5	108	105	EIAR/CIMMYT
Gibe1-158-1-1-1-1/CML197//142-1-e	11.0	107	105	EIAR/CIMMYT
CML442/F7215//142-1-e	10.3	120	112	EIAR/CIMMYT
SC22/124-b (109)//142-1-e	10.9	106	104	EIAR
IL00' E-1-12-4-1-1/CML197//142-1-e	10.7	105	102	EIAR/CIMMYT
CML395/CML202//144-7-b	8.2	112	107	EIAR/CIMMYT

Source: National Maize Research Project Progress Reports (2001–2010). EIAR = Ethiopian Institute of Agricultural Research.

Table 5. Mean yield of promising intermediate maturing single cross hybrids evaluated and identified across locations in different trials.

Pedigree	Mean yield (t ha^{-1})	Percentage of check		Sources of parents
		BH540	BH543	
X1264DW-1-2-1-1-1/DE-78-Z-126-3-2-2-1-1 g	10.6	125	114	EIAR
Gibe1-20-2-2-1-1/CML395	10.7	126	108	EIAR/CIMMYT
Gibe1-20-2-2-1-1/CML312	10.2	120	102	EIAR/CIMMYT
Gibe-1-91-1-1/Kuleni-320-2-3-1-1-1	11.0	131	109	EIAR
30H83-5-1-1-1-1-1/CML312	11.4	132	123	EIAR/CIMMYT
DE-78-Z-126-3-2-2-1-1/Gibe1-91-1-1-1-1	10.1	121	123	EIAR
F-7215/Gibe-1-20-2-2-1	10.3	114	113	EIAR
CML395/CML312	10.7	115	118	CIMMYT
30H83-5-1-1-1-1/SC22	9.5	116	110	EIAR

Source: National Maize Research Project Progress Reports (2001–2010). EIAR = Ethiopian Institute of Agricultural Research.

Table 6. Mean yield of promising intermediate maturing three-way cross hybrids evaluated and identified across years and locations in different trials.

Pedigree	Entry mean yield (t ha^{-1})	Difference from check (%)		Source of parents
		BH540	BH543	
Kuleni0080-4-2/SC22//124-b (109)	11.6	114	121	EIAR
CML395/CML202//30H83-5-1-3-2-1-1	13.1	128	136	EIAR/CIMMYT
CML312/CML442//30H83-7-3-4-1	11.2	110	117	EIAR/CIMMYT
30H83-9-1-1-1//CML312/CML442	10.6	123	110	EIAR/CIMMYT
CML395/CML202//(LZ956343/LZ956003) -B-1-1-2-B-B/124-b(113)-3-1-1	11.7	130	119	EIAR/CIMMYT
CML312/CML442//CML464	11.9	132	109	EIAR/CIMMYT
CML395/CML202// CML464	11.5	113	106	CIMMYT
CML312/CML442//(LZ-956343/LZ956003)-B-1-1-2-B-B/124-b(113)-3-1-1	11.1	109	113	EIAR/CIMMYT
CML464/SC22//124-b (109)	10.8	106	110	EIAR
CML312/CML442//(DRBF2-60-1-2-B-1-B-B-B/F-7215)-1-1-3	11.3	111	115	EIAR/CIMMYT
CML202/CML395//SZSYNA99-F2-7-2-1	11.1	109	111	EIAR/CIMMYT
CML395/CML202//(DRBF2-60-1-2-B-1-B-B-B/F-7215)-1-1-3	11.4	112	116	EIAR/CIMMYT
CML395/CML202// (LZ-96077/LZ966225)-B-3-2-2-B-B/F-7215)-3-1-1	11.0	108	106	EIAR/CIMMYT
CMLl312/CML442//X1264DW-1-2-1-1	11.6	129	106	EIAR/CIMMYT
CMLl395/CML202//X1264DW-1-2-1-1	11.5	128	106	EIAR/CIMMYT
CML312/CML442//Gibe-1-20-2-2-1	10.7	119	119	EIAR/CIMMYT
SC22/124-b (109)//Gibe-1-20-2-2-1	10.6	118	118	EIAR/CIMMYT
CML312/Gibe1-91-1-1-1-1//DE-78-Z-126-3-2-2-1-1(g)	12.3	143	113	EIAR/CIMMYT
CML312/CML442//DE-78-Z-126-3-2-2-1-1(g)	10.8	126	120	EIAR/CIMMYT
SC-22 /124-b (109)//Gibe-1-91-1-1 -1	10.9	140	131	EIAR
CML395/CML202//Kuleni-320-2-3-1-1-1	10.2	131	123	EIAR/CIMMYT
DE-78-Z-126-3-2-1(g)/CML395//Gibe-1-91-1-1 -1	12.3	143	106	EIAR/CIMMYT
CML312/CML442//SZSYNA99-F2-7-2-1	11.5	126	115	EIAR/CIMMYT
CML395/CML202//Gibe-1-91-1-1 -1	10.6	135	127	EIAR/CIMMYT

Source: National Maize Research Project Progress Reports (2001–2010). EIAR = Ethiopian Institute of Agricultural Research.

Grain yield performances of the aforementioned experimental materials are substantially better than previously released varieties. This could be attributed to mobilization of a wide range of germplasm from diverse sources and their manipulation in the breeding program to generate more advanced elite materials containing favorable alleles for yield and other desirable traits. Generally, progress made over time to develop high yielding hybrids and OPVs (Fig. 1) is encouraging and hence indicates the possibility of making further progress in the development of more advanced superior cultivars.

Development of Open-Pollinated Varieties

In some developing countries the majority of farmers often plant OPVs rather than hybrid varieties. The major factors forcing small scale farmers to refrain from using hybrids is absence of a well-developed seed industry, lack of capital and low level of agricultural practices. Availing improved OPVs as an alternative variety is an important step in Ethiopian maize farming practices. Improved OPVs, apart from using as commercial stock, could also serve as source material for extraction of inbred lines in a breeding program where hybrid varieties are the ultimate product. Therefore, the improvement and development of OPVs is often performed using recurrent selection schemes. New populations could be also formed by recombining and/or intermating superior genotypes, and also high yielding superior populations can be identified from exotic sources. This section highlights population improvement, synthesis and identification of new and adapted populations.

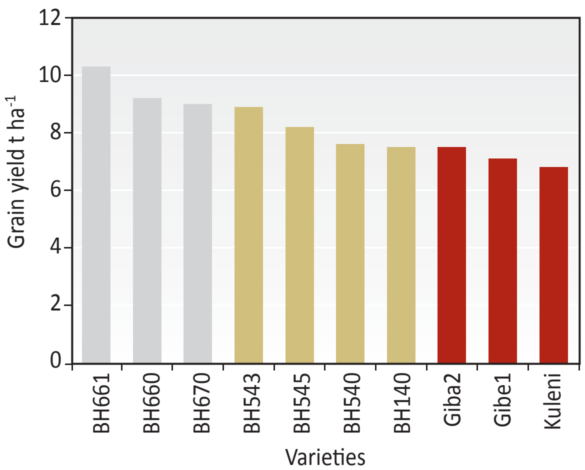

Figure 1. Progress achieved in yield performances of maize varieties (late and intermediate hybrids, and open-pollinated varieties) developed and released over the years.

Population improvement

The late maturing composite from Tanzania, so called "Ukuruguru Composite B" (UCB) was well adapted and cultivated in Jimma and Illu-Ababora zones in the southwestern part of the country. The variety possessed a good level of disease resistance and had high yield under favorable weather conditions. Root and stalk lodging were the major problems of UCB, caused mainly by its very tall plant height and high ear placement. Two cycles of S_1 recurrent selection in UCB resulted in a significant reduction in plant height (30.8 cm), ear placement (39.6 cm), and lodging severity. Further, considerable grain yield benefits relative to the commercial medium maturing OPVs, Gibe1 and Kuleni of 3.1 t ha^{-1} and 2.6 t ha^{-1}, were recorded, respectively. The improved version of UCB (Morka) has been verified and recommended for commercial production in the western long season high rainfall regions of Jimma, Illu-Abobora and Keffa zones (Leta *et al.,* 2004)

Formation of synthetics/composites

Improved populations have been constituted locally by inter-mating elite genotypes identified based on their *per se* and test cross performances. Several medium maturing OPVs have been formed locally and most of them are under further improvement, while one of them has been found to be a promising candidate (Table 7).

Table 7. Mean yield of promising OPVs evaluated across years and locations.

Pedigree	Mean yield (t ha^{-1})	Percent of check		Maturity class	Adaptation	Origin
		Gambela Comp1	Gibe1			
ZM721	7.7		110	Medium	Mid-altitude	CIMMYT
BLWBAM synth.	8.2		113	Medium	Mid-altitude	Local
Obatanpa	6.0	105		Medium	Low-altitude	Ghana
07 ZAM POP 3	8.0		112	Medium	Mid-altitude	CIMMYT
08 SADVL	8.2		115	Medium	Mid-altitude	CIMMYT
VHTB07Q SYN	8.1		120	Medium	Mid-altitude	CIMMYT

Source: National Maize Research Project Progress Reports (2001–2010).

Utilization of exotic populations

Over the years, maize germplasm consisting of inbred lines, hybrids and OPVs have been introduced from CIMMYT, IITA and the National Agricultural Research System (NARS) of different countries. Good use of these materials has been made, locally. The materials have been evaluated for their adaptation and desirable agronomic traits including grain yield and resistance to economically important diseases. One of these populations, "Gambella Composite", was identified and released for the Gambella plain in 2002. This population was introduced from IITA and has a background of maize streak virus resistance, a severe disease of maize in the area. The variety was evaluated under Gambella conditions for adaptability and tolerance to maize streak virus, and was proven to substantially exceed the standard check "Abo-Bako" by more than 15% in grain yield.

A number of promising experimental populations have been identified on the basis of their performance for grain yield (Table 7) and other desirable agronomic characteristics. Mean yield of some of these populations have significantly exceeded the standard check "Gibe composite 1" by 20% along with a good level of disease resistance and desirable agronomic traits.

Genetic Studies

Genetic study is one of the integral components and driving forces of success in plant breeding. Investigation of genetic parameters can reveal combining ability and inheritance of different traits, distinguish presence of genetic variability, indicates breeding progress, estimates breeding values and degree of heterosis, and is used to identify useful genotypes serving breeding programs. Such information assists breeders in making concrete decisions and directions on attainment of the desired objectives envisaged in the planning phase (Paliwal *et al.,* 2000). In this section an overview of genetic studies conducted in the past decade is presented.

Combining ability studies

Apart from the evaluation of cross performances at early stages of inbred line development, several studies were conducted to study general combining ability (GCA) and specific combining ability (SCA) of inbred lines for different traits. Demissew (2004) estimated combining ability of maize inbred lines for weevil resistances and reported that GCA was more important than SCA for all traits, except for the number of undamaged kernels. Dagne *et al.* (2008) studied the combining ability of selected CIMMYT and Ethiopian maize inbred lines and reported significantly higher GCA effects for gray leaf spot (GLS) disease resistance and highly significant SCA estimates for grain yield. Also Dagne *et al.* (2006) estimated combining ability of stress tolerant S_1 lines under low and optimum N conditions and reported that few cross combinations showed significant SCA effects. Mosisa *et al.* (2008) estimated the combing ability of tropical mid-altitude inbred lines, some of which are used in Ethiopia, under low and optimum N conditions in mid-altitude areas of eastern and southern Africa. They reported that the contribution of GCA to total genetic variation was higher than SCA for secondary traits under both conditions. However, they noticed a higher contribution of SCA than GCA for grain yield under low N conditions. Legesse *et al. (*2009) studied combining ability between CIMMYT and Ethiopian origin maize inbred lines and reported significantly higher GCA effects for grain yield, plant height, GLS and *turcicum* leaf blight.

Identification of testers

The consistent acquisition of testers is the most important strategy if a breeding program desires to succeed in developing and releasing superior products for commercial production. In early stages of our breeding program, two well-known heterotic testers, Kitale Synthetic II and EC573 had been widely used in the mid-altitude and transition highland maize research program of Ethiopia. These testers were used for late maturing inbred lines, where their hybrid progenies have been classified as full season maturity groups. Later, when a broad based hybrid development program was launched in the early 1980s, a line tester SC22 and a population tester, Gutto LMS 5, were used to discriminate medium maturing genotypes of diverse origins.

During the past decade, with the intensification of research activities, the search for additional and more refined testers was largely intensified mainly through the mobilization of diverse types of germplasm in the breeding program and the need to synthesize varieties of different products. Therefore, for late maturing genotypes, Ecuador and Kitale derived lines are used (Legesse *et al.,* 2009). For medium maturing genotypes CML312 and CML395, CML197, CML395/CML202, CML395/CML444, CML312/CML442, SC22, SC22/124b (109), Gutto LMS5 and AMS Synthetic have been widely used as testers. In addition, CML144, CML144/CML159 and Obatampa served as testers of QPM materials.

Heterosis studies

Heterosis is an expression of the phenomena of hybrid vigor resulting from the crossing of genetically different genotypes. Presence of genetic diversity among breeding materials ensures development of superior hybrids in a reliable and dependable manner. Various studies have been conducted to estimate heterosis. Leta (2004) studied heterosis and genetic diversity of seven east African maize populations and reported that, KCB and Abo-Bako, UCA and ABo-Bako and UCA and KCB were found to be the most genetically diverse populations, while A511, UCB, KCC and Bako-composite were observed to be genetically closely related as shown by the estimates of high parent yield heterosis. Dagne *et al.* (2007) estimated mid and high parent heterosis among crosses of CIMMYT and Ethiopian origin maize inbred lines and reported a 89% and 64% average level of heterosis for grain yield, respectively. Legesse *et al.* (2008) reported significant levels of mid-parent heterosis for grain yield among F_1 crosses of highland transition maize inbred lines. Also, yield superiority of more than 20% over the best hybrid check was reported for some test cross hybrids. Mosisa *et al.* (2009b) also made crosses among locally adapted populations and reported that the best variety cross Gibe/Kuleni out yielded the best OPV, Gibe 1 by 14%. Dagne *et al.* (2010) reported the presence of potential heterotic relationships between CIMMYT and Ethiopian maize inbred lines for use in hybrid and synthetic variety development.

Heterotic groupings

Establishment of heterotic groups has important implications in a comprehensive breeding program where outputs of different products are the ultimate objective. It assists exploitation of heterosis in an efficient and consistent manner through isolation of complementary lines; assertion of diversity and creation of new heterotic groups for hybrid program enhancement and development of different products (Russell, 1991; Cheres *et al.,* 2000).

Cognizant of this fact, our breeding program has been keen to assemble germplasm from various sources and classify them into different heterotic groups based on maturity and crossing performances (Mosisa *et al.,* 1996). Dagne *et al.* (2006) using two testers estimated combining ability of stress tolerant S_1 lines and reported that few cross combinations showed significant SCA effects and hence clear distinction of the lines into heterotic groups was not possible. On the other hand, Legesse *et al.* (2007), using AFLP and SSR markers fingerprinted transition highland maize inbred lines and reported that both marker types distinctly separated the inbred lines into different groups, mainly associated with pedigree records. Likewise, Legesse *et al.* (2009) using population and inbred line testers separated the same inbred lines into different heterotic groups on the basis of grain yield SCA values. Inbred line testers were found to be better than population testers in assigning the inbred lines into distinct groups. In the case of population testers few cross combinations showed significant SCA values and hence clear distinction for most of the inbred lines was not possible. This is because of the fact that the inbred lines were known to have some degree of genetic relationship with population testers, and hence the method, unlike the molecular markers, failed to distinguish closely related inbred lines (Legesse *et al.,* 2009). Recently, heterotic groups and formation of heterotic populations have been initiated and are further enriched with incoming new germplasm (Mosisa *et al.,* unpublished data).

Molecular marker studies

In most developing countries, the conventional method of breeding is essentially applicable for maize improvement. This method, as compared to molecular markers, has some draw backs, but it remains the best method for plant improvement. This is because it serves to select experimental materials tested across years and locations and then recommends the best varieties for commercial production. On the contrary, molecular markers are more accurate and faster in identifying differences among breeding materials. However, the methods consume considerable resources and some of them are quite complex to work with. Using these tools, the relationship of genotypes can be clearly and accurately assigned maize inbred lines into heterotic groups for hybrid breeding, predicting hybrid performances and detecting quantitative trait loci (QTL), as well as being able to develop new crop varieties of significant value (Gopo, 1999).

Despite the importance of molecular markers for maize improvement worldwide, very little information is available in an Ethiopian maize breeding context. The application of molecular markers for diversity analyses has been used in maize inbred lines using SSRs and AFLPs. Genetic diversity estimates from 21 mid-altitude maize inbred lines using AFLP markers, have shown considerable variability among tested materials. The inbred lines were also classified into distinct classes that led to the formation of heterotic groups and the ease of identifying heterotic patterns for the formation of hybrid crosses (Legesse *et al.,* 2006a, b). On the other hand, comparisons of two marker systems, AFLP and SSR, in the study of genetic diversity of transition highland inbred lines have shown substantial variability. The authors also reported the usefulness of SSR markers for diversity studies in terms of cost effectiveness and its technical ease as compared to AFLP markers.

In another study AFLP markers were also applied to genotype highland transition maize inbred lines for prediction of hybrid performances; nevertheless, the information was not of high practical significance for hybrid prediction (Legesse *et al.,* 2008).

In general, molecular markers are more dependable and quicker as compared to morphological markers; however, they are resource dependent and some of them are complex to work with. In developing countries where resources are a limiting factor, use of resource efficient and less complicated markers is advisable (Legesse *et al.,* 2007).

Harvest index studies

Several parameters are applicable to examining progress realized over time in a breeding program. One of these parameters used for this purpose is assertion of harvest index of maize varieties released for commercial production. Besides, grain yield assessments of the varieties could also give good indices of the progress. Mosisa and Habtamu (2007) estimated harvest index and grain yields of improved maize varieties released from the 1970s to the 1990s for commercial production. They reported that mean harvest index among 20 germplasm lines varied from 31.1% to 45.0%, also mean grain yield across environments varied from 4.3 t ha^{-1} (EAH75) to 7.3 t ha^{-1} (BH660). Berhanu (2009) also indicated the progress in harvest index for maize experimental varieties developed in recent years. He reported that mean harvest index across three locations among 63 hybrids ranged from 43.6% to 53.1%. Grain yield varied from 7.1 t ha^{-1} to 11.9 t ha^{-1}.

Genotype × Environment Interaction

Phenotypic expression of germplasm is inherently influenced by the effects of the environment, genetic effects and their interaction. The effect of these interactions significantly varies between locations and seasons. Consequently, some varieties show stable performances, while others fail to reveal stability across testing locations and years. The phenomena impede progress from selection and have important implication for the testing and variety release process (Kaya et al., 2002). Therefore, identifying genotypes that possess the greatest yield stability or that reveal minimum interaction with the environment under good management conditions is an important consideration in areas where environmental fluctuations are considerable.

Stability of genotypes across testing locations

Several studies have been carried out to identify stable varieties across different environmental conditions in the mid-altitude ecologies. Wende *et al.* (2004) and Wende *et al.* (2006) studied stability of genotypes which included five released and five promising experimental genotypes across 15 locations with altitudes ranging from 1,650 to 2,240 masl and reported that BH660 and Gibe1 were most stable genotypes, whereas Kuleni and BH140 were least stable. Mosisa and Habtamu (2008) also reported results obtained among 20 maize varieties tested across nine locations. None of the varieties showed high yielding stable performances under all environmental conditions. However, BH660 was found to show relatively good performance in the mid- to high-altitude (1,650–2,240 masl), whereas, BH140 and Gibe1 had good performances in the low-mid to mid-altitude (1,100–1,650 masl) areas.

Solomon *et al.* (2008), in a study conducted to determine stability performance of 15 released and promising varieties across nine locations, reported that 30H83, BH540, Ambo Synth1 and BH543 were the most stable genotypes for grain yield. The authors also further categorized the locations into three classes based on estimates of environmental indices, hence Bako, Hawassa and Hirna under favorable environments, Arsi-Negele and Areka under intermediate environments and Awada, Gofa and Jinka under unfavorable environments for maize cultivation.

Interaction of genotypes by N levels

Genotypes are not only responsive to weather conditions prevailing in certain regions and seasons. Soil conditions that are associated with the amount and types of nutrients available under the plant root zones also influence growth and development of crop varieties. Nitrogen is among the major nutrients largely limiting the yield potential of maize genotypes and it is one of the major nutrients required in large quantities. Accessibility of this nutrient in the form of inorganic fertilizer is unaffordable to resource poor farmers in developing countries. Investigations to identify relatively high yielding genotypes that can perform under a range of nitrogen levels are critical.

Several studies established that genetic correlation between maize grain yield under low nitrogen and high nitrogen is generally positive but decreases with increasing relative yield reduction under low N (Bäzinger *et al.,* 1997; Mosisa *et al.,* 2008). Wende *et al.* (2007) tested different maize genotypes under low and optimum N conditions at Bako and reported presence of genetic variation among tested materials for the efficiency of nutrient utilization and the possibility of releasing nutrient efficient commercial varieties. Mosisa *et al.* (2007a) reported that N utilization and N-uptake are important features for genotypes to express high yielding potential under low N conditions in mid-altitude adapted maize hybrids.

Dagne *et al.* (2008) evaluated QPM hybrid varieties under optimal and low N conditions and reported that hybrids with desirable endosperm modification, protein quality and stable performance can be produced under both conditions. Similarly, Mosisa *et al.* (2007b, 2009a) reported that for both non-QPM and QPM genotypes the quantity of total grain protein, endosperm lysine, tryptophan and protein contents were influenced by N level in the soil. However, QPM maize genotypes maintained their superiority to non-QPM varieties in lysine and tryptophan content in all environments.

Evaluation of genotypes under residual moisture

Exploitation of residual moisture during the dry season could be an alternative option for increasing maize production in areas where residual moisture is available in bottom lands. This practice is an existing phenomenon in different regions of the country. However, maize varieties released for main season production could not be directly recommended due to their interaction with dry season weather conditions.

Maize varieties well adapted to residual moisture conditions were not available. In 2004 an experiment involving different types of hybrids and OPVs were evaluated during the off-season at Arjo district, east Wollega region, under residual moisture without supplementing irrigation and fertilizer application. On the basis of the yield performances, Gibe1 and BH140 have been found to be suitable varieties for residual moisture conditions and recommended for dry season production (NMRP, 2007).

Breeding for Special Traits

Maize has a multitude of exploitable benefits, owing to its wide range of genetic diversity. Several types of maize varieties such as QPM, yellow maize, baby corn, pop corn and sweet corn are well known for their special characteristic features. Of these, pop corn has attractive market values owing to its popping features and this has enabled it to possess aesthetic value at coffee ceremonies in Ethiopia, particularly during holidays. Despite the importance of pop and sweet corn as high value crops, no worthwhile breeding work had been undertaken at the national level until recently. Breeding to identify high yielding pop corn varieties is timely to enhance alternative sources of income to farmers. In 2010, an experiment consisting of four introduced pop corn varieties were evaluated at nine locations. One pop corn variety was selected and proposed for release in 2011/12.

Sweet corn is not commonly grown in Ethiopia but can have an attractive market as a commercial product with economic growth of the country and expansion of international market. Introduction and evaluation of sweet corn genotypes for local adaptation is in progress. On the other hand, little research has been done in our project on baby corn, despite its importance as high value product in developed economies. Research activities carried out on QPM and yellow maize have been presented in separate papers.

Conclusion and Future Direction

In this review it has been attempted to elucidate maize research advancement accrued over the last ten years in the mid- and low-altitude sub-humid maize breeding program. It mainly describes achievements recorded to date. During this period, both conventional hybrids and OPVs have been released and recommended for commercial production and a number of others have been identified as promising cultivars for future use. Also, several inbred lines with appreciable *per se* and cross performance have been generated from local and exotic sources. These varieties and inbred lines could substantially improve the sustainable supply of more advanced commercial products to the farmers. Genetic studies referring to combining ability, heterosis and heterotic groupings, testers, harvest indices and molecular markers are good sources of basic information for enhancement of the breeding program.

Global warming is a menace to food security especially in sub-Saharan countries largely due to uncertainty in weather conditions. The on- and off-set of rainfall becomes unpredictable. Crops could fail due to shortage of moisture or extended rainy seasons and manifestation of unexpected pest incidence. To adapt to such challenging problems, highest consideration is rendered to develop choices of varieties differing in maturity, and tolerance to economically important diseases and pests.

A breeding program without strong germplasm screening facilities for disease resistance under controlled laboratory/greenhouse and field conditions is most likely to suffer from the consequence. Reliance on opportunistic screening conditions in the field is not dependable. Therefore, in order to cope with and overcome the danger of disease and insect pests and thereby develop stable and high yielding varieties, the breeding program should be strongly complemented with sufficiently equipped laboratories and greenhouse facilities along with well trained personnel.

In a comprehensive maize breeding program, establishment of a range of heterotic populations will enhance breeding activities and accelerate development of high yielding varieties. Currently, there is good initiation in this respect within our breeding program and this should be further expanded to identify a choice of source materials.

Maize breeding environments in Ethiopia are broadly classified into four major agro-ecologies. Nevertheless, a wide range of differences are prevalent in weather conditions within certain ecologies. Determining the most suitable domain for the production of a certain variety is one of the current limitations in maize cultivation. Limited budget and logistical problems are hampering performance assessment of varieties across a range of diverse localities.

Wise use of irrigation water to accelerate maize production and productivity is one of the steps to secure sustainable food supply to our country. However, varieties responsive to irrigation conditions are limited. Due emphasis will be rendered to identify best varieties efficiently yielding under irrigation and residual moisture conditions.

Currently, one of the major problems in certified seed production of hybrids is an asynchrony problem. Although this is one of the major challenges in maize hybrid breeding, investigation to identify good nicking inbred lines with good levels of heterotic response is on-going in our breeding program and it will be strongly fostered.

Since recent years, molecular studies are widely applicable in maize improvement programs worldwide. However, molecular studies presented here are all from thesis research findings, enhancement of molecular research in our breeding program substantially accelerates and complements conventional breeding activities and hence greatly facilitates product development and delivery in a short period of time.

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Maize Improvement for Low-Moisture Stress Areas of Ethiopia: Achievements and Progress in the Last Decade

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Introduction

Maize (*Zea mays* L) is one of the most important cereal crops in Ethiopia, ranking second in area coverage and first in total production. Although it is one of the strategic crops for the achievement of food security in the country, more than 90% of the production is handled by small-scale farmers under rain-fed growing conditions (CSA, 2008). About 40% of the total maize growing area is also located in low-moisture stress areas, where it contributes less than 20% to the total annual production (Mandefro *et al.,* 2002). The low yield in these areas, like other sub-Saharan African countries, is mainly attributed to recurrent drought, low levels of fertilizer use, and low adoption of improved varieties (CIMMYT and IITA, 2010).

Previously, unlike maize growing areas with adequate rainfall, few improved open-pollinated varieties (OPVs) were released for low-moisture stress areas of the country by higher learning institutions. However, the Ethiopian Institute of Agricultural Research (EIAR) started full-fledged research for the low moisture stress areas relatively recently and this has been expanding over the years.

In addition to drought, increased population pressure, high farm input costs, and extreme poverty, force smallholder farmers in these areas to implement low input farming systems. Furthermore, drought stress is intensifying aggressively and increased incidence of drought is expected as climate change intensifies (Hillel and Rosenzweig, 2002). Since resource poor farmers have limited access to irrigation, development and cultivation of drought tolerant maize varieties is vital to reduce food insecurity and poverty in the stress areas of the country. It is also reported that the maize genotypes bred for drought tolerance at flowering have improved performance under moderate nitrogen stress (Bänziger *et al*., 1999) and at high plant density (Mugo *et al.,* 2003) that broadens their adaptation. Although drought tolerant varieties (DTVs) have several additional benefits to small-scale farmers in the low moisture stress areas (LMSAs), just a few of them are listed below: (1) provide incentive to farmers to reduce maize area, diversify crop production and replenish soil nutrient deficit; (2) lead to reduced price fluctuation in drought years; (3) reduce need for imports and food aid; and, (4) greater dignity for people in LMSAs. This paper briefly discusses achievements and progress of maize improvement research during the last decade, and suggests future direction for increasing maize productivity in low-moisture stress areas of the country.

Importance of Low-Moisture Stress

It is believed that no other environmental factor limits global crop productivity more severely than water deficit (Boyer, 1982). Environments with low moisture stress are characterized by wide fluctuations in precipitation; in quantity and distribution within and across seasons (Swindale and Bidinger, 1981). Moreover, frequent and severe drought is one of the expected threats of global climate change and variability (CIMMYT and IITA, 2010).

Rainfall is extremely erratic in sub-Saharan Africa (La Rovere *et al*., 2010). Earlier reports indicated that severe drought occurs each year in at least one country within eastern and southern Africa, resulting in frequent crop failure (Waddington *et al*., 1995). This stress affects about 61–87% of the land mass in Ethiopia, Kenya and Sudan (Sanders and McMilan, 2001). Currently, it is considered the number one threat to maize production in Africa, especially in sub-Saharan Africa (La Rovere *et al*., 2010). For instance, severe drought struck maize farmers in eastern Africa in 2005/06 and again in 2009 (CIMMYT and IITA, 2010). Maize is most susceptible to this stress at flowering and often results in barrenness and serious yield instability at the farm level (Bolaños and Edmeades, 1996; Vasal *et al*., 1997).

On the other hand, it has to be recalled that tropical climate soils in general are more nitrogen deficient as compared to that of temperate climates (Edmeades *et al.,* 2006). In areas where the probability of drought stress is high, small-scale farmers often tend not to invest in yield-enhancing inputs like nitrogen fertilizer; which further contributes to lower crop productivity (CIMMYT and IITA, 2010). Furthermore, poor natural resource management especially in soil and water conservation and organic matter replenishment contributes to low productivity of maize under resource poor farmers' fields. Generally, all these confirm the importance of improving small-scale farmers' livelihoods and their conditions for production especially in areas with low moisture stress to fight poverty in Ethiopia.

Low-Moisture Stress Agro-Ecological Zones of Ethiopia

The major agro-ecological zones (MAEZs) of Ethiopia were reclassified and increased from 18 to 32 in 2005 (MoARD, 2005). According to this classification, about 51% of the total land area of the country is under arid, semi-arid and sub-moist zones. This contradicts Mati (2005) who reported 70% of the total land mass of Ethiopia as dry land (Table1; Fig. 1). This large disparity between the two reports should be further investigated to obtain a clear picture of the moisture stress areas of the country.

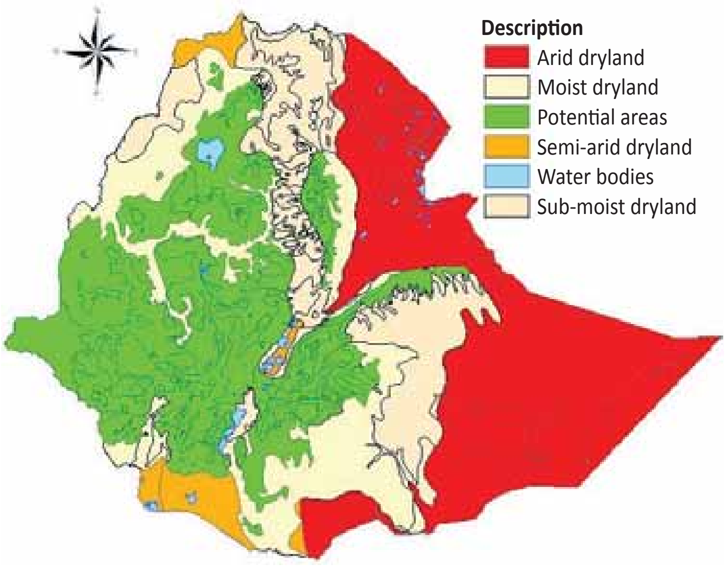

Figure 1. Agro-ecological zones of Ethiopia.

Table 1. The 32 major agro-ecological zones of Ethiopia with their respective area coverage.

No.	Major agro-ecological zones (MAEZs)		Area (ha)	% Of the country
1		Hot arid lowland plains (A1)	12,202, 262	10.87
2	Arid	Warm arid lowlands (A2)	22,356,327	19.71
3		Tepid arid mid highlands (A3)	488,137	0.43
4		Hot semi-arid lowlands (SA1)	444,794	0.43
5	Semi-arid	Warm semi-arid lowlands (SA2)	3,120,098	2.87
6		Tepid semi-arid mid highlands (SA3)	218,623	0.21
7		Hot sub-moist lowlands (SM1)	637,273	0.56
8		Warm sub-moist lowlands (SM2)	10,894,270	9.60
9	Sub-moist	Tepid sub-moist mid highlands (SM3)	5,846,476	5.21
10		Cool sub-moist mid highlands (SM4)	1,314,117	1.21
11		Cold sub-moist mid highlands (SM5)	76,812	0.10
12		Very cold sub-moist mid highlands (SM6)	18,018	0.02
13		Hot moist lowlands (M1)	872,102	0.65
14		Warm moist lowlands (M2)	17,147,667	15.12
15	Moist	Tepid moist mid highlands (M3)	9,101,092	8.03
16		Cool moist mid highlands (M4)	1,965,932	1.73
17		Cold moist sub-afro-alpine to afro-alpine (M5)	18,823	0.10
18		Very cold most sub-afro-alpine to afro-alpine (M6)	15,243	0.01
19		Hot sub-humid lowlands (SH1)	1,892,953	1.76
20		Warm sub-humid lowlands (SH2)	8,046,791	7.10
21	Sub-humid	Tepid sub-humid mid highlands (SH3)	7,515,534	6.63
22		Cool sub-humid mid highlands (SH4)	589,026	0.53
23		Cold sub-humid sub-afro-alpine to afro-alpine (SH5)	68,814	0.10
24		Very cold sub-humid sub-afro-alpine to afro-alpine (SH6)	34,889	0.04
25		Warm humid lowlands (H2)	2,592,587	2.32
26		Tepid humid mid highlands (H3)	3,065,658	2.79
27	Humid	Cool humid mid highlands (H4)	1,069,061	0.94
28		Cold humid sub-afro-alpine to afro-alpine (H5)	62,616	0.10
29		Very cold humid sub-afro-alpine (H6)	50,576	0.04
30		Hot per-humid lowlands (PH1)	13,087	0.04
31	Per-humid	Warm per-humid lowlands (PH2)	765,363	0.76
32		Tepid per-humid mid highland (PH3)	152,278	0.13
		Total	**91,353,945**	**100.00**

Source: MoARD (2005).

Breeding Strategy to Increase Maize Productivity

The average maize yield in LMSAs of Ethiopia is very low (about 1.5 t ha^{-1}) as compared to small-scale farmers with improved varieties (5 t ha^{-1}) in higher potential areas (EARO/CIMMYT, 2002). Recurrent drought, low levels of fertilizer use, and low adoption of improved varieties can be considered the main contributors to low yield as already reported for most sub-Saharan African countries including Ethiopia (CIMMYT and IITA, 2010). Under these conditions, improvement in agronomic practices and genetic stress tolerance may each reduce the yield gap by 20–30%, but the balance will depend on additional inputs such as water and nitrogen. However, for resource-poor farmers, improved seeds are more readily adopted than agronomic practices are changed (Edmeades *et al.,* 2006).

If the rainy season is reliable but very short, then escape through earliness could be a desirable breeding goal. However, as rainfall is erratic in distribution, early maturing maize varieties yield less when conditions are good. Studies have confirmed that drought at the reproductive stage or around flowering reduce productivity more than drought occurring at other periods in the crop cycle (Vasal *et al*., 1997). Thus, the recommended strategy focuses on developing high yielding, medium maturing maize varieties with tolerance to drought during flowering and grain filling stages (CIMMYT and IITA, 2010).

In the last decade, the breeding team for LMSAs of Ethiopia has implemented CIMMYT's germplasm development approach that focuses on improvement of tolerance to drought occurring at flowering and grain filling, while maintaining yield potential under favorable conditions. This method has led to the release and use of stress tolerant maize varieties with significant productivity increases under small-scale farmers' conditions. The main sources for these achievements were from the utilization of drought adaptive traits (mainly increased ears per plant and reduced anthesis-silking interval under drought stress) and screening at sites (with rain-free season) where the timing and severity of water stress can be controlled (Bolaños and Edmeades, 1996).

Achievements and Progress in Germplasm Improvement

Open-pollinated variety (OPV)

Availability of the limited number of drought tolerant maize varieties (DTMVs) that reached few smallholders was the main factor for instability and low production in LMSAs of the country. In addition, farmers' dependence on varieties with poor quality protein content has been considered as an area of research intervention. To overcome these challenges in the last decade, considerable efforts were made both in testing the adaptation of DTMVs from CIMMYT and also in enhancing drought tolerance and protein quality of the locally available elite populations. Simultaneously, the EIAR attempted to strengthen the technical capacity of the LMSA's research team through training and partnership with different CIMMYT projects like Africa Maize Stress (AMS), Drought Tolerant Maize for Africa (DTMA), and Quality Protein Maize Development (QPMD). However, about 60% of the resource was allocated to the development of drought-tolerant open-pollinated varieties (DTOPVs). As a result, the breeding team at Melkasa released one QPM and five non-QPM DTOPVs for smallholders in LMSAs of the country during the last decade. Agronomic performances of these varieties are described in Table 2. The team has been very enthusiastic and effective in discharging its responsibility. Consequently, the breeding team won awards of the 'Best Maize Breeding Team' among similar teams working for LMSAs in Eastern Africa for the last four consecutive years (2007–2010), which were presented by the DTMA Project. The team believes that strong collaborative work with CIMMYT was the main reason for these achievements and the collaboration is important for further progress.

Table 2. Mean performance of the drought tolerant maize varieties (DTMVs) released for low moisture stress areas (LMSAs) of Ethiopia (2000–2008).

Variety	Year of release	Plant height (cm)	Days to anthesis	Maturity	Seed color	Grain yield (t ha^{-1}) Research station	Grain yield (t ha^{-1}) Farmers' field	Reaction to TLB/CLR	Source
Melkasa1	2000	140–160	48	90	Yellow	3.5–4.5	2.5–3.5	Tolerant	CIMMYT
Melkasa2	2004	170–190	66	130	White	5.0–6.5	4.0–5.0	Tolerant	CIMMYT
Melkasa3	2004	170–175	64	125	White	5.0–6.0	4.5–5.0	Tolerant	CIMMYT
Melkasa4	2006	160–170	55	105	White	4.0–5.0	3.5–4.0	Tolerant	CIMMYT
Melkasa5	2008	180–190	60	125	White	3.5–4.5	3.0–4.0	Tolerant	CIMMYT
Melkasa6Q	2008	165–175	60	120	White	4.5–5.5	3.0–4.0	Tolerant	CIMMYT
Melkasa7	2008	170–182	57	115	Yellow	4.5–5.5	3.0–4.0	Tolerant	CIMMYT

Source: LMSAs Maize Research Progress Reports (2000–2010). Q = quality protein maize; TLB = *Turcicum* leaf blight, CLR = common leaf rust.

The extra-early OPVs, Melkasa1 and its QPM version (currently candidate for release) are considered as suitable for rain-fed agriculture in the SA1, SA2 and SA3 MAEZs (Table 1). Similarly, Melkasa4, Melkasa6Q and Melkasa7 varieties in combination with moisture harvesting and conserving practices can be cultivated in these three MAEZs. For the remaining drought prone areas (SM1, SM2, SM3 and SM4) and M2, any one of the OPVs from Melkasa Agricultural Research Center, except Melkasa1, can be used for production based on rainfall conditions within each MAEZ. However, DTMVs in combination with water harvesting and moisture conserving practices is always advisable since rainfall is unpredictable in LMSAs.

In addition to the released varieties, nine promising open-pollinated QPM and non-QPM genotypes were identified from the introduced materials (Table 3) and three new synthetics were developed. Four of the selected nine OPVs and two of the three synthetics are QPM. Each of the synthetics was formed by recombining 10 elite lines with desirable traits and high general combining ability (GCA). Pedigrees of the inbred lines that were used to form the QPM and non-QPM synthetics are presented in Table 4.

The QPM version of Melkasa1 (Melkasa1Q) was developed through backcrossing of Melkasa1 population with two QPM donors (CML144 and CML159), which was supported by selection of the back cross families with desirable traits both under field and laboratory conditions. In addition to its quality protein content, Melkasa1Q expressed better agronomic performances under field conditions as compared to the original Melkasa1 (Table 5). It is also believed that this extra-early variety is the best option especially for LMSAs with very short rainfall periods (Mega, Mieso, Babile, etc), where no QPM variety is available for smallholders. Thus, Melkasa1Q is expected to be released in these areas through verification in 2011 main season.

Table 3. Mean performances of the selected genotypes with tolerance to major stresses when tested at five locations.

	Grain yield t ha^{-1}		Response under no drought stress		
Pedigree	**No drought stress**	**Drought stress**	**Days to anthesis**	**Plant height (cm)**	**No. of ears/plant**
Non-QPM					
VHTA06DTSyn	7.8	3.7	68	290	1.1
(Syn01E2/DTPWC9)F2	7.6	3.5	68	294	1.2
(VP041/G16BNSeqC4)F2	7.4	3.2	68	292	1.2
(VP041/LaPostaSeqC8)F2	7.4	3.1	68	291	1.2
(Syn01DE2/Vp047)F2	7.4	2.8	68	287	1.1
QPM					
EEQPMOPV--38-EA-B-B-#-#	7.5	3.2	67	221	1.1
EEQPMOPV--45-EA-B-B-#-#	7.1	3.4	67	222	1.1
EEQPM-38-EA -#-#	7.1	3.6	67	217	1.2
EEQPMOPV--42-EA-B-B-#-#	7.1	4.0	67	220	1.2

Source: LMSAs Maize Research Progress Reports (2000–2010). QPM = quality protein maize.

Table 4. Names and general combining ability (GCA) values of the inbred-lines used to form quality protein maize (QPM) and non-QPM synthetics.

QPM inbred-lines	GCA value (t ha^{-1})	Non-QPM inbred-lines	GCA value (t ha^{-1})
[CML202/CML181]-B-B-2-B	1.5	A-511 MS 797-1-1-1-1-2-1	1.5
[CML312/GQL5]-B-B-4-B	1.3	[[[NAW5867/P30-SR]-111-2/[NAW5867/P30-SR]-25-1]-9-2-3-B-2-B/ CML388]-B-1-1-2-1-1-1	1.3
[CML389/CML159]-B-B-3-B	1.2	A-511 MS 797-1-1-1-1-1-1	1.2
[CML181/CML395]-B-B-5-B	1.1	[90323(B)-1-X-1-B/CML202]-B-2-2-1-1-1-2	1.1
[CML205/CML176]-B-B-4-B	1.0	A-511 MS 797-1-1-1-1-2-2	1.0
[BO155W/CML395]-B-B-2-B	0.9	[[[NAW5867/P30-SR]-111-2/[NAW5867/P30-SR]-25-1]-9-2-3-B-2-B/ CML388]-B-1-1-1-1-2-1	0.9
[CML202/CML181]-B-B-7-B	0.8	A-511 MS 653-1-1-1-2-2-1	0.8
[CML202/CML181]-B-B-10-B	0.8	[CML312/CML206]-B-3-3-2-1-1-2	0.8
[CML216/CML182]-B-B-5-B	0.7	A-511 MS 797-1-1-1-1-1-2	0.7
[BO155W/CML395]-B-B-2-B	0.7	A-511 MS 556-1-2-1-1-1-2	0.7

Source: LMSAs Maize Research Progress Reports (2000–2010).

Hybrids

Small-scale farmers in the LMSAs are often hesitant to expend funds for substantial quantities of agricultural inputs for crop production (CIMMYT and IITA, 2010). This was one of the main reasons for the low emphasis given to the development of hybrids during the previous decades. However, there is good evidence that hybrids maintain their advantage over OPVs in both stress and non-stress environments (Duvick, 1999; Vasal *et al*., 1997). It is generally considered that inbred lines with superior grain yield under drought conditions will provide superior hybrids under drought and low N stresses (Vasal *et al*., 1997). These studies have also suggested that hybrids developed from drought-tolerant lines combine low N tolerance and high yield potential as the best option for resource-poor farmers in drought prone areas. However, since the final evaluation of inbred lines can be best determined by hybrid performance, combining ability plays an important role in selecting superior parents for hybrid combinations.

During the last decade, about 40% of the resources of the maize improvement program for LMSAs was devoted to the development of drought-tolerant (DT) maize hybrids. As a result of this effort, a considerable number of inbred lines with high GCA and tolerance to drought were identified as indicated in Table 4. For testing their GCA and topcross performance, Obatanpa and CML144/CML159 were used as testers for the QPM inbred lines while CML395/CML202 and CML312/CML442 were used for the non-QPM lines. Currently, from the selected inbred lines, nine single crosses with promising performance under managed drought stress and rain-fed conditions at multi-sites were identified for further testing for possible release in LMSAs (Table 6).

Furthermore, 2,027 QPM and non-QPM crosses with tolerance to drought were introduced from CIMMYT, and tested for adaptation at Melkasa's quarantine trial site and then across sites in LMSAs. From these, two superior DT crosses, CML144/CML159 // Pool15QPMFS538-B-3-B-#-5-1-1-B (QPM three-way cross) and CML440/CML445// ZIMLINE/KATBCI-24-# (non-QPM double top-cross) have been identified for verification in 2011 main season for possible release. In addition, 16 DT crosses with promising performance were selected for further testing at multi-sites in LMSAs (Table 7).

Maize varieties for irrigated agricultural systems

Ethiopia has great potential for irrigated agriculture in LMSAs of the country. It is well recognized that small-scale irrigation can make a significant contribution towards reducing food insecurity both in potential and drought prone areas of the country. In addition to increasing crop productivity, it can enable farmers to increase intensification of cropping systems through double cropping and application of supplementary irrigation during dry spells and short-rain growing seasons. In spite of its potential contribution to food security, low emphasis has been given to the improvement of water use efficiency and sustainability as well as identification of suitable varieties for this growing condition. To fast track the identification of maize varieties for irrigated agriculture systems, most of the open-pollinated and hybrid varieties that have been released for rain-fed conditions were tested under furrow irrigation at different locations. From the tested OPVs, Melkasa2 was suitable for production under irrigated conditions while BHQPY545 and BH540 were superior among the hybrids (Table 8). Farmers

Table 5. Performance of quality protein maize (QPM) version of Melkasa1 (Melkasa1Q) tested across six locations along with other QPM varieties.

Name	Grain yield (t ha^{-1})	Grain yield Rank	AD (d)	ASI	EPP (cm)	PH (cm)	EH
EEQPMOPV-1-EA-B-B-#-#-#	4.6	3	60.7	1.0	1.0	160.0	73.3
EEQPMOPV-13EA-B-B-#-#-#	4.6	4	61.7	1.7	1.1	161.7	83.3
EEQPMOPV-36EA-B-B-#-#-#	6.0	1	65.3	1.0	1.0	171.7	88.3
EEQPMOPV-49EA-B-B-#-#-#	4.0	7	65.3	1.3	1.2	166.7	65.0
EEQPMOPV-33EA-B-B-#-#-#	4.4	5	64.0	1.7	1.0	163.3	78.3
EEQPM-8-EA-#-#-#	4.2	6	64.7	1.0	1.1	163.3	81.7
EEQPMOPV-33-EA-#-#-#	5.5	2	62.7	1.0	1.1	170.0	85.0
Mellkasa1Q	3.8	8	54.0	0.7	1.0	140.2	55.0
Melkasa1 (check)	3.6	9	53.3	0.0	1.1	133.3	51.7
Mean	4.3		60.5	1.1	1.1	158.5	71.3
LSD (0.05)	1.3		1.2	1.4	0.1	11.8	16.3

Source: LMSAs Maize Research Progress Reports (2000–2010). AD = days to anthesis, ASI = anthesis-silking interval, EH = ear height, EPP = number of ears per plant, PH = plant height, LSD = Least significant difference.

Table 6. Quality protein maize (QPM) and non-QPM single crosses developed from elite local inbred-lines showing superior performance under drought stress (DS) and optimal environments.

Name	Grain yield (t ha^{-1})			AD	ASI DS (d)	EPP	PH (cm)
	No DS	DS	Across 5 sites				
Non-QPM single crosses							
[CML395-4/CML202]-B-3-2-1-1-2-1/A-511 MS 797-1-1-1-1-1-2	9.7	2.6	5.8	72.4	1.0	1.0	237.7
A-511 MS 797-1-1-1-1-1-1/[CML395-4/CML202]-B-3-2-1-1-2-1	9.3	2.7	5.6	71.5	1.5	1.1	243.2
[[[NAW5867/P30-SR]-111-2/[NAW5867/P30-SR]-25-1]-9-2-3-B-2-B/CML388]-B-1-1-2-1-1-1/A-511 MS 797-1-1-1-1-1-2	9.3	3.2	5.5	70.5	2.7	1.1	210.4
A-511 MS 653-1-1-1-2-2-1/[CML312/CML206]-B-3-3-2-1-1-2	9.8	2.6	5.5	71.4	4.2	1.3	224.1
A-511 MS 653-1-1-1-2-2-1/CML395	9.3	2.3	5.5	71.4	3.3	1.2	254.1
QPM single crosses							
[CML312/GQL5]-B-B-4-1-1-1/[CML216/CML182]-B-B-5-3-1-1	9.1	2.9	5.3	73.0	1.5	1.5	192.5
[CML216/CML182]-B-B-5-3-1-1/[CML395/CML175]-B-B-5-1-1-1	9.3	3.0	5.3	71.5	2.0	1.1	227.5
[BO155W/CML395]-B-B-2-2-2-1/[CML141/[MSRXPOOL9]C1F2-205-1(OSU23i)-5-3-X-X-1-B-B]-B-B-1-5-1-3	8.0	2.6	5.1	73.3	1.0	1.0	230.0
[CML395/CML175]-B-B-5-1-1-1/[CML182/[EV7992#/EV8449-SR]C1F2-334-1(OSU8i)-1-1-X-X-3-B-B-B]-B-B-10-1-2-1	7.7	2.6	4.8	69.0	1.5	1.0	205.0

Source: LMSAs Maize Research Progress Reports (2000-2010). DS = drought stress, AD = days to anthesis, ASI = anthesis-silking interval, EPP= number of ears per plant, PH= plant height.

Table 7. Introduced CIMMYT hybrids with superior performance and adaptation in low-moisture stress areas of Ethiopia.

Name	Grain Yield t ha^{-1}			AD	ASI (d)	EPP	PH (cm)
	Melkasa	Dera	Across 5 sites				
QPM							
CML144/CML159//CML182	8.7	2.7	5.5	71.1	0.5	1.5	225.0
CML144/CML159//Pool15QPMFS538-B-3-B-#-5-1-1-B	9.8	2.7	5.3	71.1	1.0	1.7	150.0
CML445/CML144//CML159//POOL15QPMSR-B-36-B-B-B/SUSUMA	8.3	2.9	5.3	70.9	2.0	1.0	177.5
Pool15QPMFS461-B-7-B/Pool15QPMFS462-B-4-B/Pool15QPMFS538-B-3-B-#-7-1-1	7.6	3.1	4.9	68.1	1.0	1.3	177.5
Pool15QPMFS440-B-5-B/Pool15QPMFS538-B-3-B/Pool15QPMFS462-B-4-B/Pool15QPMFS319-B-2-B	7.2	2.9	4.8	67.1	2.0	1.3	212.5
CML373/CML144//CML159//POOL15QPMSR-B-34-B-B-B/SUSUMA	6.2	2.3	4.6	70.4	-0.5	1.2	160.0
Pool15QPMFS440-B-5-B/Pool15QPMFS593-B-1-B/Pool15QPMFS538-B-3-B-#-7-1-1	7.0	3.3	4.6	68.4	1.0	1.2	192.5
Pool15QPMFS788-B-3-B/Pool15QPMFS319-B-2-B/Pool15QPMFS538-B-3-B-#-7-1-1	7.7	2.1	4.5	67.1	1.5	1.3	172.5
Pool15QPMFS761-B-2-B-B-B-B/CML159/QPOPE1	6.7	2.8	4.5	67.1	1.0	1.0	167.5
Non-QPM							
CKL05004-B/CKL05018-B/CML440/CML445	8.2	3.3	5.8	69.9	1.8	1.06	130.0
CKL05003-B/CKL05017-B/CML440/CML445	8.2	2.0	5.1	70.7	1.8	0.98	130.0
CKL05004-B/CKL05022-B/CML440/CML445	8.3	1.8	5.1	71.1	2.6	0.97	115.0
CKL05003-B/CKL05022-B/CML440/CML445	7.2	1.3	4.3	71.4	2.0	1.04	150.0
AMSECA/KAT BCI - 25-#/CML440/CML445	6.4	2.9	4.6	66.2	1.2	1.16	147.5
CKL05009-B/CKL05018-B/CML440/CML445	6.9	1.2	4.0	70.7	1.1	0.92	147.5
CKL05004-B/CKL05017-B/CML440/CML445	7.6	1.2	4.4	70.9	1.7	1.08	135.0
ZEWAc2F2-#/CML440/CML445	7.0	1.5	4.3	67.9	0.6	1.11	142.5
ZEWBc2F2-#/CML440/CML445	7.7	1.5	4.6	65.1	1.8	1.04	125.0
ZIMLINE/KAT BCI - 24-#/CML440/CML445	7.1	1.5	4.3	66.9	2.0	1.03	127.5

Source: LMSAs Maize Research Progress Reports (2000–2010). AD = days to anthesis, ASI = anthesis-silking interval, EH = ear height, EPP = number of ears per plant, PH = plant height, QPM = quality protein maize.

growing maize under irrigation in the central rift valley have already ascertained the top performance of Melkasa2 and BH540 under irrigated conditions. There is also evidence that farmers at Melkasa town produced about 8 t ha^{-1} of Mellkasa2 by combining high plant population (by reducing spacing between plants from 25 to 20 cm) and supplementary irrigation. Also, preliminary results showed that BH140 performed well in the Afar plains under irrigated conditions.

Challenges and Future Direction

Availability of DT hybrids is critical to reducing food insecurity and poverty through increased productivity in the target areas. Aggressive dissemination and scaling-out activities have to be done to reach most small-scale farmers in LMSAs with the already released OPVs. In addition, development of more appropriate OPVs with superior performance over the already released lines should receive considerable attention. On the other hand, the current food security status in LMSAs and trend of low-moisture stress expansion due to climate change and variability requires more DT hybrids with high yield. To exploit this potential in the coming decade, the lion's share of the research resources should be allocated for the development of DT hybrids. Furthermore, tolerance to drought should be combined with nitrogen-use efficiency, quality protein content, and resistance to the common leaf rust, weevil, *striga* and herbicide. To implement these improvement strategies, molecular marker based selection is appropriate along with conventional breeding approaches in order to minimize the effect of G×E interaction and low heritability. Thus, it is urgent to strengthen the technical capacity and facilities in the country for implementation of molecular breeding. In addition to this, the research project should work towards the implementation of genetic stress tolerance combined with improved agronomic practices (water harvesting, moisture conservation, fertility management and improved cropping systems) and crop protection practices to exploit the full potential of improved varieties.

Table 8. Performance of the recently released open-pollinated varieties (OPVs) and hybrids under irrigated conditions at Melkasa.

Type/ Name of variety	Grain yield (t ha^{-1})	AD	PH (cm)	EPP
OPVs				
Melkasa2	8.0	66	180.7	1.1
Gambela Composite	7.3	75	216.6	1.0
Melkasa3	7.0	65	171.7	1.0
Melkasa5	6.9	68	185.0	1.1
Gibe1	6.4	75	222.2	1.0
Melkasa4	5.7	65	179.8	1.0
Melkasa6QPM	5.1	64	183.9	1.0
Abo-Bako	5.0	77	222.8	0.9
Melkasa7	4.5	63	165.2	1.1
Hybrids				
BHQPY545	9.0	78	210.1	1.4
BH540	8.4	82	226.1	0.9
BH543	7.9	83	225.8	0.9
BH140	6.6	75	202.4	1.0
BHQP542	6.6	83	215.9	1.1

Source: LMSAs Maize Research Progress Reports (2000–2010).
AD = days to anthesis, EPP = number of ears per plant,
PH = plant height.

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Development of Improved Maize Germplasm for Highland Agro-Ecologies of Ethiopia

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Introduction

A significant proportion of maize is produced in the transition and true highland zones of Ethiopia which is close to the mid-altitude zone in terms of total annual production. It is estimated that the high altitude covers 20% of land devoted annually to maize cultivation, and more than 30% of small-scale farmers in the area depend on maize production for their livelihood (Twumasi-Afriye *et al.,* 2002). In the highland areas, it is also grown as a "hunger breaking crop" for green cob consumption.

In most parts of Ethiopian highlands at elevations above 2,000 masl, farmers had been growing low yielding unimproved maize varieties. Commercial maize varieties suited to highland areas were fewer and consequently access to improved maize seed was also limited. In view of these limitations highland maize research was initiated in Ethiopia in collaboration with CIMMYT in 1997. During the period of 1997–2001, the highland maize research project made foundations of developing and classifying inbred lines into heterotic groups (Twumasi-Afriye *et al.*, 2002). Since then, these inbred lines have been used in the formation of hybrid and synthetic varieties. The varieties developed at Ambo have been made available for partner countries and national agricultural research systems (NARS) in eastern and central Africa, to evaluate under their specific environments. This paper discusses major highland maize breeding activities and achievements for non-QPM (non quality protein maize) in the 2000s and presents future directions for maize improvement in the highland agro-ecology.

Inbred Line Development and Combining Ability Studies

Following heterotic grouping of highland maize inbred lines in 2000/01, elite inbred lines were further advanced for possible hybrid formation and seed production. Currently, more than 200 elite inbred lines are available in the program, of which 60 of them have known heterotic groups on the basis of their specific combining ability (SCA) responses with three population testers namely Kitale synthetic II, EC-573 and Pool 9A (Twumasi-Afriye *et al.,* 2003).

In addition, a combining ability study was conducted for some inbred lines to determine the combining ability of transitional highland maize inbred lines among five lines and three testers (Table 1) using line by tester analysis at Kulumsa and Ambo in 2003/04. B.T.Z.T.V.C-283-B-1-1-B and B.T.Z.T.V.C-43-B-2-2-B manifested high positive SCA effects with F7215 implying these two lines combine well with F7215. B.T.Z.T.R.L.137-B-2-1-B manifested negative SCA with F7215 indicating that they could have similar genetic background. Thus, the testers showed tendency of discriminating lines into heterotic groups. B.T.Z.T.R.L.137-B-2-1-B and 142-1-e had high GCA for grain yield; whereas, maximum SCA effect for grain yield was obtained from B.T.Z.T.R.L.137-B-2-1-B/142-1-e and B.T.Z.T.R.L-71-B-3-3-B/142-1-e (data not shown). In conclusion, crosses with good SCA and high mean values can be promoted for further testing (Bayisa *et al.,* 2007).

Synthetic Variety Development

Five highland maize synthetics, AMB01Syn1, AMB01Syn2, AMB01Syn3, AMB01Syn4 and AMB01Syn5 were constituted from five different groups of inbred lines on the basis of their general combining ability (GCA) responses and *per se* performance (Twumasi-Afriye *et al.,* 2003).

Table 1. Estimates of general combining ability (GCA) effects for grain yield across locations.

Parents	GCA effect for grain yield
B.T.Z.T.R.L-71-B-3-3-B	−260.7
B.T.Z.T.V.C-283-B-1-1-B	60.9
B.T.Z.T.V.C-43-B-2-2-B	−124.6
B.T.Z.T.R.L-137-B-2-1-B	190.4
B.T.Z.T.R.L-8-B-2-1-B	134.0
142-1-e (Ecuador573)	884.2**
144-7-b (Ecuador573)	520.2*
F7215 (Kitale-Syn.II)	−1404.4**
S.E. (M)	208.0
S.E. (F)	294.1
S.E(d)gi-gj (line)	87.2
S.E(d)gi-gj (tester)	73.6

* = significant at P = 0.05, ** = significant at P = 0.01, S.E. = standard error.

In group one, AB01Syn$_1$(Hora) was composited from seven S_4 inbred lines derived from Pool-9A SR(BC_2) full sib families, namely [POOL9Ac7-SR(BC_2)]FS67-1-2-1-1, [POOL9Ac7-SR(BC_2)]FS68-1-1-1-1, [POOL9Ac7-SR(BC_2)] FS89-1-2-1-3, [POOL9Ac7-SR(BC_2)]FS108-1SR-3-1, [POOL9Ac7-SR(BC_2)]FS112-4-2-3-1, [POOL9Ac7-SR(BC_2)] FS48-1-1-1-1 and [POOL9Ac7-SR(BC_2)]FS60-2-3-1-1. In the second group of synthetic formation, six S_4 inbred lines derived from three late white transition zone materials were used in the formation of AMB01Syn2. This included B.T.Z.T.V.C 171-1-1-1 - {AMB}-1, B.T.Z.T.V.C 266-B-1-1-{AMB}-1, B.T.Z.T.V.C 266-B-1-1-{AMB}-2, B.T.Z.T.V.C 347-1-2-1-{AMB}-1, B.T.Z.T.V.C 347-1-3-2 - {AMB}-1 and B.T.Z.T.V.C 347-1-4-1-{AMB}-1. In the third group of synthetic variety development, S_3 inbred lines derived from six full sib families of Pool 9A were utilized to form AMB01Syn$_3$. The materials involved in the formation of this synthetic were [POOL9Ac7-SR (BC_2)] FS2-3SR-2-3, [POOL9Ac7-SR(BC_2)]FS45-3-2-1, [POOL9Ac7-SR(BC_2)]FS50-1-1-1, [POOL9Ac7-SR(BC_2)] FS68-1-1-1, [POOL9Ac7-SR(BC_2)]FS68-2SR-2-3 and [POOL9Ac7-SR(BC_2)]FS48-1-1-1. The fourth synthetic, AMB01Syn4, was constituted from true highland materials derived from Mexico materials. This synthetic had poor performance and as a result it was not advanced for further evaluation. The fifth synthetic, AMB01Syn5 was constituted from F_1 top crosses of Kuleni by six [POOL9Ac7-SR(BC_2)] full sib S_3 lines. Kuleni was used as male parent for the seven inbred lines. The inbred lines involved were [POOL9Ac7-SR(BC_2)] FS68-1-1-1, [POOL9Ac7-SR(BC_2)]FS89-1-2-1, [POOL9Ac7-SR(BC_2)]FS108-1SR-3, [POOL9Ac7-SR(BC_2)]FS112-4-2-3, [POOL9Ac7-SR(BC_2)]FS202-1SR-2-1, [POOL9Ac7-SR(BC_2)] FS48-1-1-1 and [POOL9Ac7-SR(BC_2)]FS60-2-3-1.

In general, similar patterns of recombination and selection were carried out to develop the five synthetics. In the process of constituting these synthetics, possible combinations were made in the year 2000 among inbred lines with good GCA. In 2001, F_1 seeds of best inbred lines were planted on isolation blocks for recombination. Then selection and subsequent recombination of best families were made to come up with distinct, uniform and stable populations with desired agronomic performances. Together with further recombination and subsequent selection, AMB01Syn1, AMB01Syn2, AMB01Syn3, AMB01Syn5 and AMH800 (Kuleni/ [POOL9Ac7-SR(BC_2)]FS48-1-1-1-1-#) were evaluated in mother-and-baby trials during the 2002 main-season. These materials were evaluated both on-station and on-farmers fields during the period of 2002 to 2004; and thus AMB01Syn1 (Hora) was officially released in 2005 (Table 2). Currently, AMB01Syn5 is under further recombination and improvement for possible release in the coming years.

Hybrid development

In addition to developing inbred lines and synthetic varieties, the highland maize research project has been developing a number of top-crosses, single-crosses and three-way-crosses and evaluating across highland representative testing sites in Ethiopia (Ambo, Holetta, Kulumsa, Haramaya, Adet, Sigmo and Areka) and other eastern and central African countries during the last ten years (Table 3). Thus, of these materials, one top-cross and two three-way-crosses namely Arganne (AMH800), Wenchi (AMH850), and Jibat (AMH851), respectively, were released for highland agro-ecologies during the period of 2005–2009 (Table 2) for public use.

Technology scaling up activities

Following the workshop for technology scale up and scale out held at the Ethiopian Institute of Agricultural Research (EIAR) in May 2006, a number of improved crop varieties developed by the institute have been scaled up for use by farmers and other stakeholders. Likewise, Hora and Arganne have been scaled up/out and/or popularized in West Shoa, and Gurage zones since 2006. During the 2008 cropping season, scaling

Table 2. Released highland maize varieties with their agro-ecological adaptation and agronomic characteristics.

Variety Type	Variety	Pedigree	Year of release	Altitude (m)	Rainfall (mm)	Days to maturity	Seed color	Yield (t ha^{-1})		Disease reaction		
								On station	On farm	GLS	TLB	CLR
Hybrids	AMH800 (Arganne)	Kuleni/[Pool9AC7-SR (BC_2)]FS48-1-1-1-1	2005	1,800–2,500	1,000–1,200	175	White	7.0–8.0	5.5–6.5	T	T	T
	AMH850 (Wenchi)	KIT-21-2-1-1-2/KIT-32-2-2-1-1//FS89-1-2-4-2-1-1-1	2007	1,800–2,600	1,000–1200	183	White	8.0–12.0	6.0–8.0	T	T	T
	AMH851 (Jibat)	FS59-4-1-2-1-1-1/FS67-1-2-3-1//KIT-23-3-3-1-1	2009	1,800–2,600	1,000–1,200	178	White	8.0–12.0	6.0–8.0	T	R	R
OPV	Hora	AMB01Syn1	2005	1,800–2,400	1,000–1,200	170	White	6.0–7.0	4.0–4.5	T	T	T

OPV = open-pollinated variety, T = tolerant, R = resistant, GLS = gray leaf spot, TLB = *Turcicum* leaf blight, CLR = common leaf rust.

up activities were carried out mainly for Arganne and Hora while the recently released variety, Wenchi, was demonstrated only around Ambo and South West Shoa. Accordingly, during the period 2005–2010, about 1,500 demonstrations and/or scaling up/out activities were conducted by the maize team, non-government organizations (NGOs) and technology scaling up-and-out team of EIAR (Table 4).

Reports from Alamata research center indicate better adaptability of AMH800 and Hora in the Ofla district of Tigray. It was reported that performance and yield of both varieties were reasonable. According to farmers' perception, AMH800 and Hora were preferred varieties with actual yield potential of 6.0 t ha^{-1} and 3.4 t ha^{-1}, respectively, while yield of the local variety was 3.2 t ha^{-1}. Though both varieties were highly appreciated by the participants of farmers' field days, AMH-800 was highly selected on a farmer's field day conducted in its grain filling stage of the season due to the reason that the variety had 2–3 ears per plant, dark green leaf color with strong stalk and earliness. Unlike the local variety, there were no diseases and insect pests observed in the improved varieties (Abrha *et al***.**, 2007).

Similarly, reports from Kulumsa Research Center revealed that Hora and Argene varieties demonstrated at four locations in Arsi Zone (Arsi Robie, Kofalle, Jeju and Chole) in 2003 to 2004 showed good performance in yield and other desirable traits.

Farmers preferred these varieties for their earliness and high yielding potential (6.3 t ha^{-1} and 8.3 t ha^{-1}, respectively) as compared to the local variety (4.2 t ha^{-1}). Furthermore, to satisfy farmers' high demand for the improved highland maize varieties and production packages, scaling-up of Hora was carried out in Arsi at three districts (Hetosa, Kofelle and Chole) during 2005–2006.

Table 3. Combined analysis of yield, some important agronomic traits and diseases of highland maize hybrids evaluated during 2006 main cropping season across ten locations (three in Ethiopia and seven in other eastern African countries) - AMB06TW12.

Pedigree	GY (t ha^{-1})	DMF (d)	DFF (d)	PH (cm)	EH (cm)	Lodging (%)	GLS (1–5)	CLR (1–5)	TLB (1–5)
[KIT/SNSYN[N3/TUX]]c1F1-##(GLS=1)-1-2-1/04PN1931/142-1-e	10.9	84	87	227	125	5.4	1.5	1.5	2.1
Jibat(AMH851)	10.8	74	76	193	107	2.4	1.6	1.3	1.5
Wenchi(AMH850)	10.0	74	78	186	101	6.1	1.7	1.4	1.5
[POOL9Ac7-SR(BC_2)]FS107-3-2-2-2-1/KN2010/142-1-e	9.3	80	84	192	109	9.2	1.6	1.7	2.1
[POOL9Ac7-SR(BC_2)]FS68-2SR-1-1-1-1/EN1852/TWP3-4	9.3	74	78	186	99	8.5	1.8	1.4	2.0
BH660	9.2	87	90	220	125	10.2	1.5	1.4	2.0
[POOL9Ac7-SR(BC_2)]FS60-2-1-1-3/01N2027/05N1842	9.1	74	77	205	109	8.3	1.9	1.4	1.9
SRSYN95[KIT//N3/TUX]F1-##(GLS=1.5)-22-2-2x PN1931/TWP3-4	9.0	78	80	190	103	5.6	1.8	1.4	2.0
[POOL9Ac7-SR(BC_2)]FS89-1-2-4-2-1/042014/142-1-e	9.0	82	86	198	114	8.9	1.7	1.5	2.1
[POOL9Ac7-SR(BC_2)]FS68-1-2-1-1-2/EN1816/05N197	8.8	74	77	193	101	6.6	2.1	1.5	2.1
LOCAL CHECK	8.8	80	84	204	127	10.4	1.9	1.3	2.1
Mean	8.8	78	81	194	108	7.4	1.8	1.4	2.1
LSD (0.05)	1.4	2	3	16	12	5.1	0.4	0.2	0.3
CV (%)	18.2	4	4	9	12	78.5	22.5	17.6	16.5
Number of locations combined	10	8	8	7	7	9	10	10	10

GY = grain yield, DMF = days to male flowering, DFF = days to female flowering, PH = plant height, EH = ear height, GLS = gray leaf spot, CLR = common leaf rust, TLB = *Turcimum* leaf blight, LSD = least significant difference, CV = coefficient of variance.

Table 4. Demonstration and scaling up activities of highland maize varieties during 2005–2010 in Ethiopia.

Year	Zones	No. of Farmers	Area (ha)	Varieties	Activities
2005	West Shoa	20	4.0	Argane, Hora	Demonstration
2006	West Shoa	210	52.5	Argane, Hora	Scaling up
2007	West Shoa and Gurage Zones	410	180.0	Argane, Hora	Scaling up
2008	West Shoa and Gurage Zones	493	181.1	Argane, Wenchi	Scaling up
2009	West Shoa	90	20.0	Argane	Farmers' research group
2009	West and South West Shoa Zones	10	21.3	Argane, Wenchi	Scaling up
2010	West and South West Shoa Zones	90	21.3	Argane, Wenchi	Farmers' research group
2010	West and South West Shoa and Arsi Zone	177	37.6	Argane, Wenchi, Jibat	Demonstration
Total		**1,500**	**517.8**		

Future Research Needs

Available potentials of existing germplasm have been exploited. Further yield advance demands incorporation of genetically variable germplasm in the program to cope with ever changing environmental factors and increasing population pressure. Hence, new germplasm must be incorporated periodically to fit changing environmental factors.

Formation of responsive and diverse heterotic pools was among the primary activities of the highland maize project during its inception in 1997. However, the target of constituting heterotic gene pools was not finalized and hence it needs due effort and inclusion in future research priority agendas.

Development of high yielding varieties alone cannot guarantee higher productivity unless integrated with improved agronomic practices, soil and water conservation measures, and strong extension services at different levels. Thus, future gains in productivity demand regular genetic improvement together with improved crop management practices focusing on specific areas.

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A Decade of Quality Protein Maize Research Progress in Ethiopia (2001–2011)

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Introduction

The production and consumption of maize (*Zea mays* L) has rapidly increased in Ethiopia since the early 1990s. Maize has assumed a significant importance in the diets of rural Ethiopia and gradually penetrated into urban centers. This is particularly evidenced by green maize being sold at road sides throughout the country as a hunger-breaking food available during the months of February to May annually. This increasing phenomenon is reinforced by the fact that maize is generally the first crop planted in Ethiopia and becomes first to be edible compared with other major grain crops such as *tef*, wheat or sorghum. These other grain crops are not only planted later than maize in the cropping season, but also need to be harvested, dried, threshed and processed before first consumption. Maize on the other hand can be eaten green right in the field even before roasting or cooking if it becomes very necessary.

Despite its increased consumption, maize, like all cereal crops, is known to be of poor protein nutritional quality. The maize protein is limited in two essential amino acids - lysine and tryptophan (Bressani, 1991; National Research Council, 1988). Protein malnutrition, therefore, occurs especially among children where maize and other cereals dominate crop production and consumption. A nutritionally enhanced quality protein maize (QPM) germplasm exists which doubles the two limiting amino acids in maize making it approach the protein nutritional quality of casein milk (National Research Council, 1988; Brewster 1997). QPM contains 90% the protein quality of casein milk compared with 40% for conventional maize (CM) (for reviews of QPM refer Atlin *et al.,* 2011). Consumers of QPM, especially children, have been shown to benefit from the improved nutrition of QPM (Akuamoa-Boateng, 2002; Bressani, 1991; Brewster *et al*., 1997; Ortega-Aleman *et al*., 2009; Rahmanifar and Hamaker, 1999; Gunaratna *et al*., 2009). On the other hand, QPM varieties adapted to Ethiopia and competitive in grain yield with cultivated conventional maize were lacking and only one QPM hybrid had been released for planting by 2001. This first released QPM hybrid, however, remained unattractive to the majority of Ethiopian farmers especially in the high potential maize growing areas because of its lower yielding potential and susceptibility to major maize diseases. This made it imperative to develop and deploy QPM varieties targeted to the major maize growing agro-ecologies of Ethiopia.

A major effort was therefore exerted to introduce finished QPM germplasm/genotypes developed elsewhere, and to convert CM to QPM followed by on-station and on-farm testing. Alongside the breeding effort, the potential benefits especially for children in rural communities as well as the usefulness of QPM in making popular Ethiopian local dishes were studied. The objective of this paper is, therefore, to review the efforts that have been made in the last decade to develop and deploy QPM germplasm in Ethiopia and to report progress and achievements attained in variety development, seed production and utilization. This will help not only to increase the dissemination of QPM varieties in Ethiopia but will also show the future direction and gaps in QPM germplasm development and dissemination in Ethiopia.

QPM Germplasm Development

QPM germplasm development in Ethiopia was part of a regional collaborative effort between CIMMYT and a regional network of national agricultural research systems (NARS) in the Association of Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) region involving research, extension and seed production personnel in the Eastern and Central Africa (ECA) countries. The effort, spanning over the last decade, involved collaborative CIMMYT/donor funded projects with large components of flow-through funding to enable the full participation of regional NARS. CIMMYT remained the major source of global QPM germplasm and hence QPM development in the region and Ethiopia heavily depended on the large pool of QPM source germplasm available at CIMMYT. In particular, the Quality Protein Maize Development (QPMD) project funded by the Canadian International Development Agency (CIDA) has greatly supported QPM germplasm development in four countries in the Horn of Africa (Ethiopia, Kenya, Uganda and Tanzania) since 2003. As part of the project, CIMMYT placed one senior maize breeder in Ethiopia to work with the national program breeders to develop QPM for the region.

The initial thrust of the improvement project was to screen for adaptation and possible direct release of QPM cultivars already released in similar agro-ecologies in Africa or elsewhere. The second approach was conversion of popular and farmer-preferred conventional maize cultivars in Ethiopia. The objective of the latter approach was to fast-track QPM delivery to farmers by maintaining the integrity of the farmer and consumer preferred characteristics of known cultivars while only altering the protein quality of the grain. The third and final approach was to embark upon QPM source germplasm development either through mass conversion of elite non-QPM inbred lines or through pedigree breeding involving proven QPM lines. The target agro-ecologies for the above activities in Ethiopia included the highland sub-humid, wet mid-altitude, and moisture-stressed mid-altitude which are served by Ethiopian Institute of Agricultural Research (EIAR) maize breeding programs at Ambo, Bako and Melkasa Research Centers, respectively, in close collaboration with CIMMYT.

QPM Variety Screening for Adaptation

In the last decade (2001–2010), 1,037 open-pollinated and hybrid QPM materials mainly from CIMMYT-Kenya were tested for adaptation and grain yield at Melkasa Quarantine Trial site and multi-sites in low-moisture stress areas. From the open-pollinated genotypes, CIMMYT Pool15QPM C7, which was relatively early in days to maturity and tolerant to the major stresses in the zone, was released as Melkasa6Q in 2008 (Table 1). One QPM hybrid, MHQ138 (CML144/CML159//Pool15QPMFS538-B-3-B-#-5-1-1-B) was also identified as superior to CM commercial checks in the drought prone areas where it will be proposed for release through verification in 2011. Laboratory analyses of above QPM varieties showed that each of the recommended QPM varieties for low-moisture stress areas had lysine contents of 3.0–4.2% and tryptophan contents of 0.8–1.0% in protein of whole grain flour, which is within the acceptable range for QPM germplasm. Other performance data of the released and candidate QPM varieties for low-moisture stress areas of Ethiopia are presented in Table 1.

Similar trials conducted in the wet mid-altitude zone by Bako Research Center identified CIMMYT single cross yellow-grained QPM hybrid CML161/CML165 as very productive and highly adapted to the zone. This hybrid had been widely released in South American countries and therefore it gained fast-tracked release in Ethiopia in 2008.

Conversion of Conventional Highland Maize Inbred Lines to QPM

A number of released and popular CM cultivars (open-pollinated varieties; OPVs, and parental inbred lines of hybrids) were converted to QPM (Table 2) following a backcross breeding procedure described by Vivek *et al*. (2008). QPM donor stocks suitable for each CM germplasm were sourced from CIMMYT maize lines (CMLs). The QPM donors were those that closely bore resemblance to each recurrent parent (RP) in terms of adaptation–environment and disease reaction. In the case of inbred lines, each QPM donor was also preferably in the same heterotic group as the RP. Details of two conversion programs are described below.

Conversion of Parental Lines of BH660 to QPM

Conversion of BH660, the most popular and widely grown three-way hybrid, began in 2003. The conversion procedure followed similar backcrossing process described above for the heterotic highland maize lines. Three CIMMYT QPM donors, CML144, CML159 and CML176, were used to convert the three parental lines of BH660: A7033, F7215, and 142-1-e, respectively. Ten 5.1 m rows of each of the

Table 1. Mean performance for major traits of the released and candidate quality protein maize (QPM) varieties for low-moisture stress areas of Ethiopia.

Name/pedigree	Grain yield (t ha^{-1})		Days to anthesis	Days to maturity	Plant height (cm)	Ear height (cm)	Kernel color	Remark
	On-station	On-farm						
Melkasa6Q	5	3.3	59	120	170	72	White	Released 2008
MHQ138 (CML144/CML159//Pool15QPMFS538-B-3-B-#-5-1-1-B)	7.5	5.2	70	140	180	98	White	Candidate for release in 2011
Melkasa1Q (QPM version of Melkasa1)	3.9	2.9	51	96	145	64	Yellow	Candidate for release in 2011
Melkasa1 (original and non-QPM)	3.8	2.8	50	94	142	62	Yellow	Released in 2000 as normal maize

three parental lines (A7033, F7215, and 142-1-e) were planted in a crossing block at Ambo Research Center alongside 10 rows each of the donors in 2003A. To ensure flowering synchrony, five rows of the donor CML lines were planted at the same time as the BH660 parents while five were planted 10 days later. At flowering, emerging shoots of the BH660 parental lines were covered with shoot bags. The CML donors served as males (pollen source) while the BH660 parental lines served as females (pollen recipient) on receptive extruded silks. A day previous to pollination of receptive silks, the donor plants with mature anthers were covered. At mid-morning pollen was collected and bulked from each donor line and was used to pollinate mature silks of respective recurrent parent. After each pollination, the shoots were immediately covered to prevent extraneous pollen and to allow growth to maturity. To speed up the process of conversion of the BH660 parents, BC_0F_1 formed in 2003A was immediately backcrossed to respective recurrent parents in 2003B under irrigation at Ambo Research Center following the same procedure described above. Thus, at harvest in 2003B, BC_1F_1 seeds were obtained. The 10 BC_1F_l rows of each of the three lines under conversion were planted in separate blocks in 2004A and plants within each line were self-pollinated to produce BC_1F_2 grains. After harvest and drying to about 15% grain moisture, each selfed ear was shelled separately. A light table was used to select seeds with endosperm modifications of 2 and 3 following the method described by Vivek *et al.* (2008). The selected BC_1F_2 were planted ear-to-row and backcrossed to respective recurrent BH660 parental inbred lines in 2004B season under irrigation at Ambo Research Center to produce BC_2F_1. The converted lines thereafter were advanced consecutively to BC_2F_6 through self-pollination followed by light table selection.

In 2008, 59 samples of sister lines of A7033Q, F7215Q and 142-1-eQ were sent to CIMMYT-Mexico Quality and Plant Tissue Analysis Laboratory for chemical analysis. Twenty seed samples were used for each line. Data obtained from the analysis showed that several lines had tryptophan contents of 0.66–0.89 g $100g^{-1}$ protein compared with 0.55–0.58 g $100g^{-1}$ protein for non-QPM inbred line checks (Table 3). Protein contents of the lines were 10.4–13.1 g $100g^{-1}$ sample and were comparable to those of the non-QPM checks and protein quality index ranged from 0.66 to 1.27 g $100g^{-1}$ compared with 0.55 to 0.58 g $100g^{-1}$ for the CM checks (Table 3). This showed conclusively that the converted BH660 parental lines could now be classified as QPM according to standards (tryptophan >0.65 g $100g^{-1}$ protein and protein >0.8 g $100g^{-1}$ sample) prescribed for QPM by Vivek *et al*. (2008).

A7033Q, one of the parental lines of BH660, was found to be very poor in grain modification and therefore in 2006 attempts were made to find a replacement line for it in the formation of the QPM version of BH660. This

Table 2. Conventional maize germplasm converted to quality protein maize (QPM) in Ethiopia.

Material	Origin of source germplasm	Number of genotypes	Description	Year completed
Inbred line parents of BH660 (A7033, F7215, 142-1-e)	Ethiopia	3	Parental lines of BH660 three-way hybrid, most popular variety in mid-altitude and transitional highland zones	2009
KULENI	Ethiopia	1	Released OPV for highland zone	2010
BH670 (144-7-b)			Male parent of BH670	Ongoing
Melkasa1	Ethiopia	1	Released OPV for highland zone	2010
A511	Ethiopia	1	Released OPV for highland zone	Ongoing
East Africa transitional/highland materials				
AMB01SYN1	CIMMYT-Ethiopia	1	POOL 9A SR S4 with high GCA synthetic (*turcicum* tolerant)	2009
AMB01SYN2	CIMMYT-Ethiopia	1	T-ZONE LINES with high GCA synthetic (*turcicum* tolerant)	Discontinued
AMB01SYN3	CIMMYT-Ethiopia	1	POOL 9A SR S3 with high GCA synthetic (*turcicum* tolerant)	Discontinued
AMB01SYN5	CIMMYT-Ethiopia	1	POOL 9A SR/Kuleni synthetic (*turcicum* tolerant)	Discontinued
Partial conversion of East Africa transitional/highland lines to derive source germplasm				
Kitale Heterotic Group	CIMMYT-Ethiopia	69	Lines with *turcicum*/MSV/GLS tolerance	2008
Ecuador Heterotic Group	CIMMYT-Ethiopia	64	Lines with *turcicum*/MSV/GLS tolerance	2008
Pool 9A Heterotic Group	CIMMYT-Ethiopia	34	Lines with *turcicum*/MSV/GLS tolerance	2008

OPV = open-pollinated variety, MSV = maize streak virus, GLS = gray leaf spot, GCA = general combining ability.

involved finding late maturing converted highland lines and CIMMYT QPM CMLs which could combine well with the remaining two BH660 parental lines – 142-1-eQ and F7515Q. The objective was to form a BH660 QPM version involving two of its original converted parental lines but with A7033Q replaced. The hybrids were subsequently evaluated in multi-location trials in 2008.

In January 2007, the top-performing single crosses involving converted lines and either 142-1-eQ or F7215Q were identified and planted following their evaluation in line x tester trials.

A preliminary QPM version of BH660, "BH660Q", was formed in the off-season of 2005 at Melkasa with the objective of using it to gather data on expected field performance of the converted version concurrently with the continuing improvement of grain modification and protein quality of the parental lines. In 2006 main-season, 10 rows each of BH660 and BH660Q were planted in observation plots at Ambo station and on-farm for observation. Preliminary evaluation showed that the two hybrids were not easily distinguishable based on plant phenotype. Further evaluation was carried out in multi-location trials in 2007 and 2008. Several crosses of 142-1-eQ and F7215Q were formed using the highland converted lines with known good performance in their non-QPM forms and tested them in 2007 and 2008 trials. Inbred lines such as CML491, CML502, FS68Q, and Ecu34Q were used in place of A7033Q as the third parent to reconstitute the QPM version of BH660. Standard recommended agronomic practices for the planting zones were followed. Row spacing in the trials was 0.75 m and plant spacing 0.25 m with row length of 5.1 m. The Ministry of Agriculture (MoA) fertilizer recommendations in the zones of the trials were followed. All standard agronomic data were taken. The QPM versions of BH660 along with the CM version and commercial checks were evaluated on-station and on-farmers' fields between 2006 and 2010 inclusive at high- and mid-altitude locations in Ethiopia.

Results of field evaluations of BH660Q showed that grain yield was not compromised by the conversion (Fig. 1). However, the conversion resulted in slight earliness to silking compared to BH660 as well as lower plant and ear heights (Fig. 1, Table 4). The replacement of the line A7033 which had poor modification was also successful. Three lines, CML491, FS68Q and ECU34Q, combined well with 142-1-eQ with the resultant three-way hybrids producing comparable grain yield with BH660Q (Table 5). The three-way hybrid FS68Q/142Q//CML491 had the best grain modification similar to

Table 3. Protein quality of sister inbred lines of BH660 parental lines converted to QPM and analyzed at the CIMMYT-Mexico Quality and Plant Tissue Analysis Laboratory in 2008.

Lab number	Pedigree	Protein (g 100 g^{-1} sample)	Tryptophan (g 100 g^{-1} protein)	Quality index
15594	142-1-EQ-1-1-1-1-#	11.8	0.2	1.3
15592	142-1-EQ-1-1-1-2-#	11.3	0.2	1.3
15593	142-1-EQ-1-1-1-3-#	10.5	0.1	1.3
15596	142-1-EQ-1-1-1-8-#	11.6	0.1	1.1
15590	142-1-EQ-1-1-1-9-#	11.7	0.1	0.9
15589	142-1-EQ-1-1-1-6-#	10.8	0.1	1.0
15588	142-1-EQ-1-1-1-5-#	10.4	0.1	0.9
15583	A7033Q-1-2-#	12.5	0.1	0.9
15569	A7033Q-1-1-2-1-#	12.8	0.1	0.7
15575	A7033Q-1-1-5-5-#	12.3	0.1	0.7
15573	A7033Q-1-1-5-1-#	12.1	0.1	0.7
15570	A7033Q-1-1-2-2-#	13.1	0.1	0.6
15543	F7215Q-1-11-1-#	11.8	0.1	0.9
15525	F7215Q-1-1-1-#	11.0	0.1	0.9
15568	F7215Q-3-6-#	11.8	0.1	0.8
15554	F7215Q-1-10-#	11.9	0.1	0.8
15528	F7215Q-1-2-3-#	11.5	0.1	0.8
15545	F7215Q-1-1-#	11.8	0.1	0.7
15566	F7215Q-3-4-#	12.1	0.1	0.7
15533	F7215Q-1-3-1-#	10.8	0.1	0.8
15535	FS48 (Non-QPM Check 1)	11.3	0.1	0.6
15577	FS48 (Non-QPM Check 2)	10.3	0.1	0.6
15556	FS48 (Non-QPM Check 3)	10.4	0.1	0.6

QPM = quality protein maize

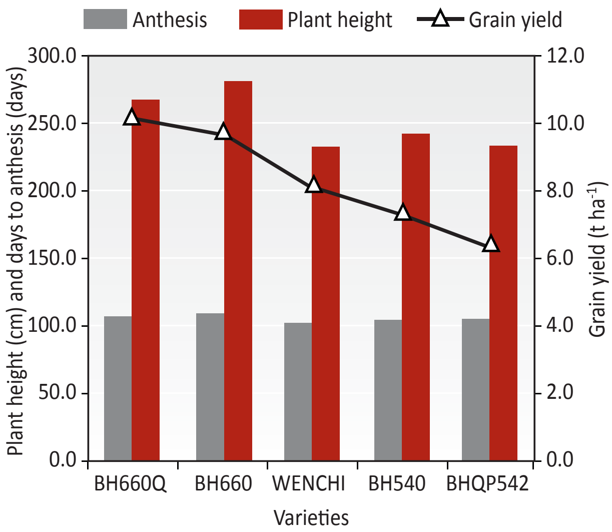

Figure 1. Comparative performance of Ethiopian commercial hybrid BH660 and its quality protein maize (QPM) converted counterpart BH660Q evaluated at three highland sites in Ethiopia in 2006.

BH660 (Table 5). Consequently, three of the BH660-type hybrids were nominated and presented to the Ethiopian National variety Release Committee (NVRC) in 2010 for final field verification and release in 2010. The NVRC approved the release of F7215Q-1-11-1-#/142-1-EQ-1-1-1-3//A7033Q-1-1-5-1-#-# as AMH760Q in February 2011

Conversion of Melkasa1 to QPM

The QPM version of Melkasa1 (Melkasa1Q) was developed through backcrossing of Melkasa1 maize population with two QPM donors (CML144 and CML159), and by selection of superior families with desirable traits from each of the three back-cross cycles both under field and laboratory conditions.

Table 4. Grain yield and agronomic performance of conventional and QPM versions of BH660 and check varieties at five sites in Ethiopia in 2008.

Variety Name	Grain yield (t ha^{-1})	Days to anthesis	Plant height (cm)	Ear height (cm)	Root lodging (%)	Stem lodging (%)	Common rust (1–5)	*Turcicum* leaf blight (1–5)	Ear aspect (1–5)
BH660Q	10.1	107	267	165	0.0	0.0	1.5	1.5	2.1
BH660	9.8	109	281	175	10.3	5.3	1.7	1.5	2.1
WENCHI	8.1	102	233	129	0.0	0.0	1.3	2.3	2.4
BH540	7.3	104	243	129	6.0	4.4	1.7	2.2	2.2
AMH800	7.0	101	234	126	2.2	3.6	1.8	2.2	2.6
CML144/CML159//SUSSUMA C1FS3-3-1-1-1-#	6.6	103	221	114	5.6	7.3	1.8	2.3	2.5
CML144/CML159//SUSSUMA C1FS8-2-3-1-1-#	6.4	103	231	118	14.2	9.2	2.0	2.5	2.5
BHQ542	6.3	105	233	116	7.8	7.3	2.0	2.3	2.4
Mean	7.7	104	243	134	5.8	4.6	1.7	2.1	2.4
LSD (0.05)	0.8	1.9	12	9	4.7	5.1	0.4	0.6	0.2
No. significant sites	5	3	4	4	2	1	1	1	4

LSD = least significant difference

Table 5. Performance of hybrids involving BH660 parental lines converted to quality protein maize (QPM) and crossed with other highland QPM lines tested at four locations in Ethiopia in 2008.

Pedigree	Grain yield (t ha^{-1})			Days to anthesis				Height (cm)		Kernel modification (1–5)
	Bako	Ambo	Mean	Male	Female	Plant	Ear	Bako	Ambo	Mean
FS68Q/142Q/CML491	11.1	6.9	9.0	100.0	101.0	284.0	158.0	1.8	1.5	1.6
ECU34Q/142Q//CML491	10.1	7.4	8.7	97.0	100.0	269.0	153.0	2.5	1.8	2.1
BH660Q (142Q/CF7215Q//A7033Q)	9.4	7.8	8.6	95.0	97.0	278.0	163.0	2.3	1.3	1.8
FS195Q/142Q//CML491	8.4	8.1	8.2	96.0	99.0	268.0	148.0	2.5	2.0	2.3
FS68Q/142Q//CF7215Q	7.7	8.6	8.2	95.0	96.0	279.0	160.0	3.3	2.5	2.9
WENCHI Non-QPM	8.8	7.4	8.1	89.0	93.0	223.0	118.0	1.0	1.0	1.0
FS4Q/F7215Q//CML491	9.5	6.3	7.9	99.0	101.0	269.0	159.0	2.3	2.0	2.1
JIBAT Non-QPM	9.0	6.9	7.9	91.0	94.0	270.0	139.0	1.5	1.0	1.3
BH660 Non-QPM	9.4	6.3	7.8	100.0	100.0	296.0	191.0	1.5	1.5	1.5
ECU34Q/142Q//F7215Q	8.1	6.7	7.4	93.0	97.0	266.0	146.0	3.8	3.0	3.4
ECU3Q/142Q//CML491	9.3	5.3	7.3	96.0	98.0	269.0	153.0	3.3	2.0	2.6
FS48Q/F7215Q//CML491	7.6	5.6	6.6	96.0	98.0	255.0	135.0	1.5	1.3	1.4
FS48Q/F7215Q//CML502	7.5	5.3	6.4	95.0	97.0	268.0	123.0	2.8	2.5	2.6
FS195QQ/142Q//F7215Q	6.3	5.7	6.0	93.0	96.0	258.0	150.0	3.5	2.0	2.8
Mean	8.7	6.7	7.7	95.0	98.0	268.0	150.0	2.4	1.8	2.1
CV (%)	13.6	11.2	12.9	2.0	3.0					
LSD (5%)	2.6	1.6	1.4	3.0	4.0					

LSD = least signicant difference, CV = coefficient of variance.

These conversion activities took seven years mainly due to kernel color differences between the donor parents (white) and recurrent parent, Melkasa1 (yellow). Twenty-two BC_3F_2 segregates with similar kernel color to the original Melkasa1 and tryptophan level of more than 0.88% were selected and recombined in isolation fields for two seasons. For recombination, 40 seeds from each of the selected families were bulked and planted in isolation fields for random mating. Then, again the F_1 synthetic was advanced to F_2 in an isolation field during the 2009 main-season. The laboratory analyses results indicated 3.9% lysine and 0.9% tryptophan of total protein in whole grain flour of the QPM version of Melkasa1 (Melkasa1Q), while relatively better agronomic performances in-field across seven trial sites as compared to the original Melkasa1 (Table 1). The observed data have confirmed that this extra-early variety is the best option especially for areas with very short rainfall period within the drought prone areas (like Mega, Yabelo, Mieso, Babile, Jijjiga etc.), where there is no QPM variety available for small-scale farmers. Thus, Melkasa1Q is expected to be released for resource constrained farmers in these areas through verification trials in 2011.

Conversion of Conventional Maize Inbred Lines to QPM

The source germplasm used to convert CM to QPM were highland maize inbred lines developed in the CIMMYT/NARS Highland Maize Breeding Project for eastern and central African countries (ECA) and already characterized into heterotic groups (Twumasi-Afriyie *et al*., 2002, 2003, 2004) at Ambo, Ethiopia. The backcross conversion procedure was used to convert the inbred lines to QPM. In the inbred line conversion, 21, 10 and 20 lines in Ecuador, Pool 9A, and Kitale already characterized into heterotic groups, respectively, were used. The CM lines served as RPs while the CMLs from CIMMYT served as QPM donors. CML144 was used as the QPM donor for lines in the Ecuador Group while CML176 was used for the lines in Pool 9A and Kitale heterotic groups (Table 2). In the main-season of 2001 (2001A), the 51 highland lines and the donor parents were planted in a crossing block in isolation at the Ambo Research Center of EIAR. Each line was planted in one row of 5.1 m with 0.75 m between rows and plant spacing of 0.25 m. There were 21 plants per row. Each QPM donor was planted in an adjacent block of 24 rows in a similar manner. To ensure flowering synchrony, the donor parents were planted at two different dates – half block of 12 rows was planted on the same date as the RPs and the other half 10 days later. Before anthesis, all emerging shoots of the RPs were covered with plastic shoot bags. At flowering time, hand-pollinations were carried out. Tassels of donor parent plants with mature and viable pollen were covered with pollination bags a day prior to their use. On the day of pollination, the pollen from the donor parent was bulked by shaking them in the pollination bags. Pollination was accomplished by dusting the extruded silks of the CM inbred lines with the pollen while the pollination bags were used simultaneously to cover the ear shoots. Pollination was continued until virtually all plants within RP rows had received pollen and thus BC_0F_1 seeds were obtained from each RP at harvest.

BC_0F_1 ears were separately harvested together for each recurrent parent, air-dried and each ear was shelled separately in seed envelopes. In 2002A, each BC_0F_1 ear was again planted in 5.1 m rows. At flowering time, about 15 plants per row were self-pollinated by dusting the extruded silk of each plant with its own mature pollen. Thus BC_0F_2 ears were obtained. At harvest, only BC_0F_2 ears with visible segregating opaque-2 grains were selected, shelled and bulked for each line under conversion. Air-dried BC_0F_2 grains were placed on light tables as described by Vivek *et al*. (2008) and grains with scores of 2 and 3 were selected. In 2002B (off-season irrigation), selected BC_0F_2 grains of each line under conversion were planted adjacent to its recurrent parent in an isolation block at the Ambo Research Center of EIAR. At flowering time, pollen grains from the recurrent parents were used to pollinate each BC_0F_2 plant to obtain BC_1F_1 ears. In 2003A, 5.1 m rows of BC_1F_1 were planted and advanced to BC_1F_2 as described above for BC_0F_1. Similar to the BC_0F_2, light table selection was done to obtain grains with scores of 2 and 3 to continue the conversion process. The second backcrossing was achieved as described for BC_1 above at the Ambo Research Center in 2003B (off-season irrigation) and thus BC_2F_2 lines were obtained. In order to improve grain modification of the converted lines as well as select for good agronomic characters and disease resistance (diseases such as rust, *turcicum*), BC_2 was advanced to BC_2F_6 through selfing followed by plant and ear selection in the field and light table selection of well-modified grains in the laboratory. Alongside the QPM backcrossing process, BC_1F_1 and BC_2F_1 crosses were also used to develop inbred lines through continuous inbreeding.

In 2006, 20 grains of BC_2F_5 lines with modification scores of 2 and 3 of each line were sent to CIMMYT-Mexico Quality and Plant Tissue Analysis Laboratory for tryptophan analysis following the procedure outlined by Nurit *et al*. (2009). Results of grain sample analysis at CIMMYT-Mexico showed that 230 and 107 converted CM inbred lines (including sister lines) were phenotypically stable with protein levels of 8–14 g 100 g^{-1} protein and tryptophan levels 0.065–0.087 g 100 g^{-1} protein (Table 6). Since maize germplasm with protein levels >8.0 g 100 g^{-1} protein and tryptophan >0.06 g 100 g^{-1} protein are considered as QPM (Vivek *et al*., 2008), this showed that these lines could be classified as QPM. Based on previous heterotic group classifications of the recurrent CM lines used for the backcrosses, we obtained QPM converted lines in all three heterotic-group classifications (Twumasi-Afriyie *et al*., 2002) namely, Pool 9A, Ecuador, and Kitale (Table 6). Field evaluation of single cross hybrids constituted from the converted lines showed that there were single crosses that produced higher grain yield than the released QPM three-way hybrid BHQP542 (data not shown). Furthermore three-way cross hybrids evaluated in 2008 in the highland zones of Ethiopia that showed cultivars could be developed from the converted lines with higher grain yield than BHQP542 (Fig. 2). This

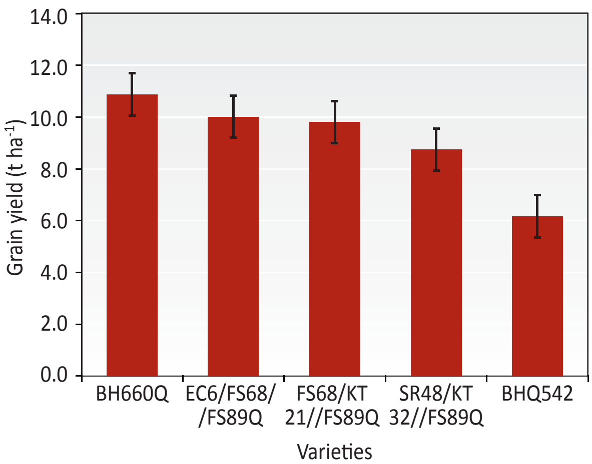

Figure 2. Grain yield of experimental varieties formed from highland inbred lines converted to quality protein maize (QPM) and evaluated at three sites in Ethiopia in 2008.

showed that QPM germplasm are now available for variety development for the highland zones of Ethiopia. These lines are available on request from CIMMYT/ EIAR Highland Maize Project based at Ambo Research Center, Ambo, Ethiopia.

Improvement of Obatanpa for Resistance to Major Maize Diseases in the Highland and Mid-Attitude Zones of Ethiopia

Several versions of Obatanpa (QPM OPV originally released for the lowland in Ghana) were released in the ECA region. While the variety is highly productive, it is usually attacked by the major leaf diseases in the region especially *Puccinia sorghi* and *Exerohilum turcicum*. A project was initiated to improve the disease tolerance of Obatanpa using its version Susuma from Mozambique as the source material in 2003. In 2005, 100 S_3 lines derived from Susuma were planted in two replications and evaluated at Ambo and Bako in Ethiopia and Namulonge in Uganda. The materials planted at Ambo and Bako were artificially inoculated with *E. turcicum* and grey leaf spot (GLS) diseases, respectively. The materials planted at Namulonge were evaluated for GLS and *turcicum* under natural conditions. The lines at Ambo that showed disease tolerance were self-pollinated for further evaluation and selection. In 2006A season, 100 S_4 lines were planted at Ambo and at the same time samples were sent to Mexico for lab analysis.

Results analysis of Obatanpa (Susuma) lines at the CIMMYT-Mexico Quality and Plant Tissue Analysis Laboratory showed that 92 lines had acceptable tryptophan levels of 0.060–0.097% (data not shown). Subsequently, Obatanpa inbred lines with improved disease resistance were used to form single cross and

Table 6. Protein quality of highland maize inbred lines converted to quality protein maize (QPM) and analyzed at the CIMMYT-Mexico Quality and Plant Tissue Analysis Laboratory, 2008.

Material	QPM donor	Number with 0.065%<TRP<0.087%	Number with 0.050%<TRP<0.054%	Breeding status
Highland CM inbred lines conversion to QPM				
Kitale heterotic group	CML176	98	76	BC_2F_6
Ecuador heterotic group	CML144	66	29	BC_2F_6
Pool 9A heterotic group	CML144	66	29	BC_2F_6
Total	CML144	230	134	BC_2F_6
QPM inbred line development from F_2 populations				
Kitale heterotic group	CML176	37	70	BC_1F_6
Ecuador heterotic group	CML144	35	49	BC_1F_6
Pool 9A heterotic group	CML145	35	49	BC_1F_6
Total		107	168	

CM = common maize, TRP = tryptophan.

three-way hybrids. After further disease screening in Ethiopia and Uganda, two synthetics were constituted from the lines and evaluated in Ethiopia and Uganda along with the original Obatanpa checks. One improved synthetic is currently under national performance trialing in Uganda for possible release to replace the disease susceptible version of Obatanpa, Nalongo, which is currently under cultivation in the country.

Replacement of CML176 as Parental Line of the Hybrid BHQP542

The first released QPM variety in Ethiopia, BHQP542, had the pedigree CML144/CML159//CML176. The hybrid was soon found to succumb to diseases especially *E. turcicum* and *P. sorghi* in some environments. It was soon realized that the culprit for the disease susceptibility of the hybrid was its male parent CML176. Replacement of CML176 therefore became crucial in an Ethiopian context after several discussions among CIMMYT, Saskawa Global 2000 (SG2000), Ethiopian Seed Enterprise and EIAR. Basically, there was an urgent need for a better QPM variety in the mid-altitude wet zones in the region especially in Ethiopia where rust and *turcicum* are serious diseases plaguing the released QPM variety. Without more adapted QPM varieties in the zone, the enthusiasm of farmers already whipped and hyped by extension messages on the enhanced nutrition of maize would turn to disappointment, especially in Ethiopia. Immediate replacement of the culprit line CML176 from extensive dissemination was required. A committee of breeders was formed in Ethiopia to identify a good replacement line. The following steps were taken: (1) crosses were made between the single cross, CML144/CML159, and several Obatanpa and other QPM inbred lines that had good tryptophan levels and disease tolerance developed by EIAR breeders at Bako and Melkasa, CIMMYT-Ethiopia and CIMMYT-Kenya, (2) several evaluations were undertaken using the replacement hybrids in multi-location trials in Ethiopia. Field performance data showed that several Susuma and highland CM converted lines could replace CML176 in the released hybrid BHQP542 and they performed better in its target zone (Table 7).

Yellow Endosperm QPM

In collaboration with the national maize breeding program at Bako, one yellow endosperm QPM had been identified for rapid seed increase, multi-location evaluation and possible release in Ethiopia. The hybrid CML161/CML165 was the same one that was identified in 2004 for Abu Diyab Poultry Farm near Ziway in Ethiopia for possible use in the poultry farm. However, the poultry business was unable to produce the hybrid. Seeds of the parental lines and the hybrid were obtained from CIMMYT-Mexico for seed increase in the off-season of 2006/07 at Bako followed by rapid field assessment for possible release in Ethiopia. The field evaluation data (not shown) collected in 2008 and 2009 and presented to the National Variety Release Committee showed that the hybrid had good performance in the mid-altitude agro-ecologies of Ethiopia. The hybrid was therefore released as BHQPY545 in 2008.

Table 7. Top performers of quality protein maize (QPM) replacement inbred lines crossed to CML144/CML159 and evaluated at four sites in Ethiopia in 2006.

Pedigree	Grain yield Across (t ha^{-1})	% BHQP542	Days to silking	Plant Height (cm)	Ear Height (cm)
CML144/CML159//SUSSUMA C1FS3-3-1-1	9.4	174	113	145	68
CML144/CML159//SUSSUMA C1FS160-1-1-1	9.3	172	111	125	63
CML144/CML159//[KIT)-21-2-1-#/CML176BC1F1-2-1	9.1	169	113	145	79
CML144/CML159//SUSSUMA C1FS160-1-1-1	8.7	161	110	129	67
CML144/CML159//SUSSUMA C1FS8-2-3-1	8.1	150	117	150	87
CML144/CML159//[KIT-12-2-1-#/CML176BC1F1-4-2	8.0	148	114	141	77
CML144/CML159//P9AFS222-1-2-2-1-#/CML176BC1F1-3-1	8.0	148	110	148	76
CML144/CML159//SUSSUMA C1FS112-1-2-1	8.0	148	111	156	88
CML144/CML159//SUSSUMA C1FS181-2-2-1	7.8	144	113	142	77
BH540	7.0	130	112	159	97
BH542	5.4	100	113	142	76
Mean	7.1	–	113	3	142
LSD (0.05)	1.9	–	5	6	19
CV	16.2	–	3	127	8

LSD = least significant difference, CV = coefficient of variance.

QPM Nutritional Studies

The major cereals in Ethiopia in terms of farm production and consumption are *tef* (*Eragrostis tef*), maize, sorghum, wheat and barley (CSA, 2010). '*Injera*', a fermented thin flat pancake-like bread with evenly distributed honeycomb eyes, is a major national dish widely consumed on a daily basis by many Ethiopians. *Tef* is commonly used to prepare *injera*, however, other major cereals in Ethiopia have increasingly been used either entirely or in mixtures with *tef* to prepare *injera* probably driven by the rising price of *tef*. In terms of cereal crops productivity per unit area, *tef* ranks among the lowest in the country (CSA, 2010). Thus maize, as the most productive cereal crop in Ethiopia, could be attractive for making *injera* but for its poorer physico-chemical properties, maize is not preferred by most Ethiopians for making *injera*. Since the introduction of QPM into the farming systems of Ethiopia, unpublished data have revealed that farmers and *injera* consumers in rural Ethiopia preferred QPM grain for *injera* making quality above conventional maize .

Asrat *et al*. (unpublished) studied QPM, conventional maize and other common Ethiopian cereal grains for their nutritional quality, proximate analysis, functional properties and sensory evaluation. The authors prepared various combinations of *injera*, bread, porridge and *anebabero* (thick *injera* without the honeycomb eyes). In addition to this, various recipes of other QPM-based foods were also developed. It was shown that QPM grain was composed of 10.8% moisture, 9.9% protein, 4.9% fat, 70.7% carbohydrate, 2.2% crude fiber, 1.6% ash, 7.2 mg 100 g^{-1} of calcium, 3.8 mg 100 g^{-1} of iron and 373.81 calories. Unlike the conventional maize, QPM-based foods were highly preferred by a panel of tasters and had superior baking qualities that resulted in softer and less fragile *injera* and bread. QPM based *injera* also had a relatively longer shelf life without having much effect on its softer texture. Furthermore, compared with the conventional maize QPM *injera* developed a less sour taste during the fermentation process. These improved functional properties of QPM recipes made it more palatable and increased the preference in utilization of QPM in the preparation of complementary foods. Further, it was reported that porridge made from QPM was smoother as compared to the conventional maize. Finally, this study concluded that the use of QPM in traditional food preparations such as *injera* and porridge could contribute to household food security and reduce malnutrition among children based on its nutritional value, functional properties, and food preference (Asrat *et al*., unpublished).

Akalu *et al*. (2010) conducted two 1-year-long studies on the effectiveness of QPM in improving the nutritional status of young children in the Ethiopian highlands. The first study involved 151 children aged 5 to 29 months using cluster-randomized design while the second study used a completely randomized design with 211 children aged 7 to 56 months. The studies were conducted in maize growing zones where there was widespread malnutrition and maize was dominant in complementary foods of children. In each of the studies, half of the households were provided with QPM seed and the other half with seed of an improved conventional maize variety with similar plant characteristics. In both studies, there was a positive effect on growth of children of farmers who grew QPM and consequently consumed it. In the first study, a positive effect of QPM was observed for weight but not height, with children in the QPM group recovering from a drop in weight-for-height (WHZ) (Fig. 3). Children in the QPM group recovered to WHZ values comparable with those at baseline. Children in the QPM group grew an average of 167 g/month compared with an average of 146 g/month during the 13-month study for children in the conventional maize group. This is a significant (15%) increase in the rate of growth in weight among children in QPM households. In the second study, while children consuming QPM did not change significantly in height-for-age and had a marginal increase in weight-for-age, children consuming conventional maize progressively faltered in their growth. The two studies together showed that children in predominantly maize consuming communities could reduce or prevent growth faltering and may in some cases support catch-up growth in weight. In general, these conclusions were in agreement with those found elsewhere that QPM could significantly impact the nutritional wellbeing of maize consuming communities (Akuamoa-Boateng, 2002).

Potential Contribution of QPM to Improvement of Food Insecurity in Ethiopia

A study was conducted in four eastern African countries including Ethiopia in 2007–2008 to determine the importance of maize in these countries and to what extent QPM could have an impact on food security and diets. The study focused on QPMD target areas which in Ethiopia covered zones in the Southern Nations, Nationalities, and Peoples' Region. Surveys were conducted in the selected zones to determine whether the necessary conditions were met for QPM to have an impact on food consumption and improved nutrition. Small-farmer food crop production dominated the economies of the QPMD target zones in all countries. The maize crop formed a major component of the cropping system and was also a major source of the staple diets. Maize-based cropping systems in which maize was grown either as a pure crop or in crop mixtures were in Uganda (42%), Ethiopia (56%) and Kenya (58%) to almost all systems in Tanzania (95%). The study found that food insecurity was a major problem in the selected zones with Ethiopia having about 50% of households in the area being severely food insecure while up to 90% of the households in Ethiopia were severely or moderately food insecure (Fig. 3). The prevailing high food insecurity was seasonally high during the pre-harvest months.

Maize was found to be a dominant contributor of protein to the human diets in the study areas since the consumption of protein from other sources such as legumes or animals was relatively low (Fig. 4). According to Young and Pellett (1990), households where animal and/or legume derived protein formed less than 40% of protein intake are at risk of insufficient lysine in their diets, even in times of relative food abundance. Consequently, it could be deduced that 88% of households in Ethiopia, 56% in Uganda, 46% in Tanzania, and 41% in Kenya were at risk of inadequate lysine intakes during the post-harvest period (Fig. 4). Therefore, the study concluded that improving the nutritional quality of the maize grown in areas such as those in QPMD target areas could have significant potential in improving the nutritional status, health, and wellbeing of these populations. The study specifically singled out southern Ethiopia as the most likely to benefit from consumption of QPM, given the very poor quality of diets, even during the post-harvest season, and the heavy reliance on maize.

Conclusions

A decade of sustained QPM germplasm development has led to significant achievement in the development and deployment of nutritionally enhanced maize in Ethiopia. Popular released conventional maize cultivars were successfully converted to QPM during the period. The most significant of these was the successful conversion of BH660 the most popular hybrid in Ethiopia and its release as AMH760Q in 2010. This hybrid, AMH760Q, is equally adapted to the range of high potential maize growing ecologies in Ethiopia covered by BH660. Combined with the imminent release of the QPM version of Melkasa1 for the drought-prone areas of Ethiopia it will greatly increase availability of nutritionally enhanced maize to farmers. In addition to this, a large pool of cultivars, both OPVs and hybrids, can now be developed from the source germplasm developed through the mass conversion of the conventional highland maize inbred lines to QPM. Alongside the germplasm development studies conducted during the period it has been shown that QPM made better local foods such as *injera*, bread and porridge than CM. Furthermore, it was shown that children living in communities predominantly depending on maize could greatly benefit from consuming QPM through reducing or preventing growth faltering and in some cases supporting catch-up growth in weight. QPM therefore has bright prospects in contributing greatly to the food security in Ethiopia.

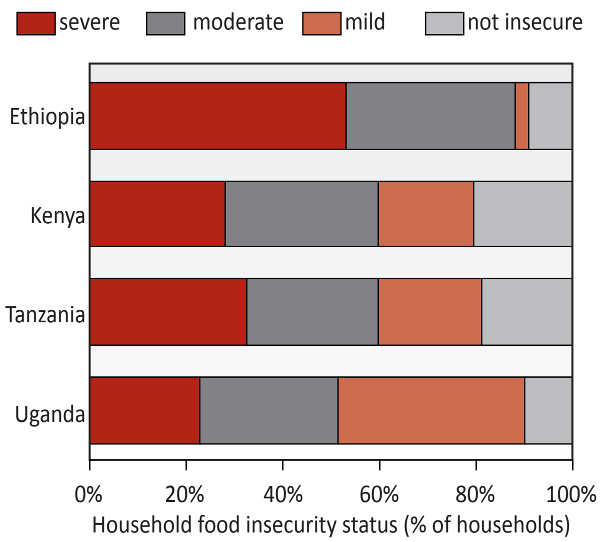

Figure 3. Distribution of household food insecurity in study areas (Source: Quality Protein Maize Development—QPMD— Final Report).

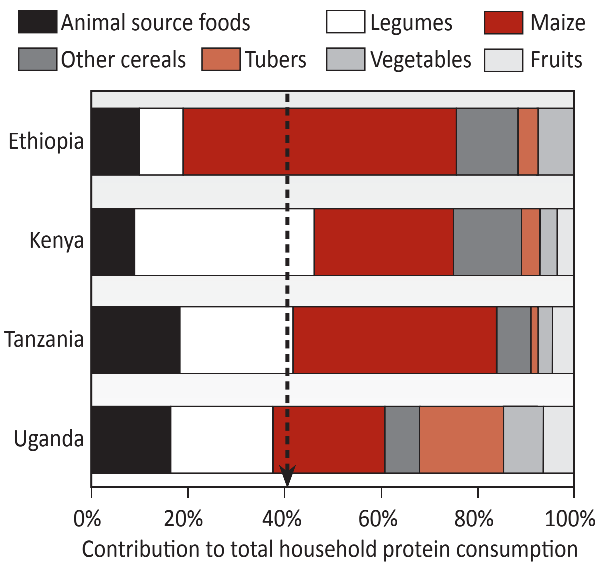

Figure 4. Sources of protein in the household diet in study areas in the month preceding the survey (Source: Quality Protein Maize Development—QPMD— Final Report).

Future Prospects

- There is the need to use the increased pool of QPM source germplasm currently available to develop farmer-preferred cultivars targeted to the diverse maize growing zones in Ethiopia.
- Further multi-location evaluation of promising QPM varieties already developed or identified for possible release for smallholder farmers.
- A major effort in dissemination of QPM is required that should involve not only the conventional on-farm variety demonstrations but also nutritional education for rural and urban maize consumers using modern communication avenues such as the radio and mobile phones.
- QPM germplasm should be further biofortified with other micronutrients such as iron and vitamin A.
- QPM development along with other nutrient biofortification should be well integrated into the national research agenda gradually increasing human and financial resource allocation so that eventually all or most maize varieties developed should be nutritionally enhanced.
- Develop functional seed systems/seed roadmaps to avail seeds of released varieties to farmers.
- A strengthened human and material capacity for in-country laboratory analysis of biofortified maize grains during the breeding process will be necessary for continued rapid progress in developing nutritionally enhanced maize.
- Finally, in the coming years modern molecular biology tools such as doubled haploid technology, marker assisted selection, high throughput and precision phenotyping and breeding informatics should be increasingly integrated into QPM breeding to speed up the QPM development process as well as increase cost-efficiency.

Acknowledgements

We are greatly indebted to the Federal Government of Ethiopia and the Government of Canada (through Canadian International Development Agency; CIDA) for playing a leading role in significant financial and human resource allocation to QPM development in Ethiopia. We appreciate the tremendous sacrifices offered by the Ethiopian Agricultural Research Institute research centers in supporting QPM and its development. We also thank CIMMYT and its numerous partners for providing human, material and technical backstopping to QPM development in Ethiopia particularly through its numerous donor-supported projects of Eastern and Central Africa.

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Development of Improved Yellow[1] Maize Germplasm in Ethiopia

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Introduction

Comprehensive reviews of maize breeding research over the past decade targeting the major Ethiopian maize agro-ecologies can be referred to in a range of articles in this publication. In this article, we focus on research on yellow maize improvement. We admit that yellow maize is not genetically very distinct from its white counterpart, nor is the technique of its breeding unusual. However, this focus on yellow maize germplasm enhancement stems from a recently established end-use demand driven need for a yellow maize breeding program in Ethiopia. Additionally, we wish to highlight the value of yellow maize as an economically and nutritionally important food and feed crop in Ethiopia. This paper will provide an overview of how breeding research for yellow maize was initiated, and indicate the achievements, current status and the way forward in relation to yellow maize improvement in Ethiopia.

Some Facts About Yellow Maize

Firstly, it would be worth highlighting some of the key features of this colored variant of maize. Yellow maize is basically identical to white maize except for its grain color which has yellow to orange shades of color due to the presence of chemical compounds known as carotenoids, mainly in the endosperm. Yellow maize is usually preferred to white maize as livestock feed for it bestows a yellowish color on poultry meat, egg yolk and animal fat, which is widely preferred by consumers in many countries (FAO and CIMMYT, 1997; Egesel *et al.*, 2003; McCann, 2005).

Yellow maize contains both pro-vitamin A and non pro-vitamin A classes of carotenoids which have potential health benefits for humans (Abebe *et al.*, 2008). In fact, yellow maize is the only naturally available cereal that is known to accumulate a significant amount of the essential micronutrient vitamin A in the seed, in the form of pro-vitamin A carotenoids (Callison *et al.,* 1952; Egesel *et al.*, 2003). Studies have also demonstrated the promising bioavailability of pro-vitamin A in maize (e.g. Howe and Tanumihrdjo, 2006; Li *et al.,* 2010). However, the concentrations of pro-vitamin A in commonly grown maize varieties are inadequate to meet the vitamin A requirement of the human body (FAO and CIMMYT, 1997). There is an ongoing international research endeavor to improve endosperm pro-vitamin A concentrations in commonly grown maize using the crop's inherent diversity in carotenoid accumulation. It is hoped that such a biofortification strategy will serve as a sustainable approach to help alleviate vitamin A deficiency and its consequences among millions of people in the developing world where maize is a major staple crop (Hoisington, 2002; Bouis and Welch, 2010).

The yellow endosperm phenotype of maize is assumed to have originated as a naturally occurring variation due to a gain-of-function mutation in the gene known as Y1 or PSY1, which is involved in carotenoid biosynthesis in the maize seed. This trait has been a target of breeding since the early twentieth century, following the recognition of the nutritional benefits of increased carotenoids in yellow maize (Palaisa *et al.*, 2003). Yellow-grained maize constitutes the largest proportion of maize produced and consumed globally, mainly as animal feed (FAO and CIMMYT, 1997; McCann, 2005). World production of yellow maize is over 500 million tons, which is more than seven times the production of white maize (McCann, 2005). The current prevalence of yellow phenotypes is believed to be entirely the result of human artificial selection that occurred in the past century (Palaisa *et al.*, 2003).

White kernelled maize is the predominant maize type in Ethiopia in consonance with other African countries where more than 90% of the total maize crop is white but in contrast with the predominant color composition of world maize (FAO and CIMMYT, 1997; McCann, 2005), both in terms of production and consumption. While it can be argued that many present-day maize farmers are less familiar with yellow maize, maize varieties having colored kernels are not totally new to the maize farmer in Ethiopia. The earliest (seventeenth century) maize introduced in the country was probably red colored and the existence of yellow maize cultivation in Ethiopia is evident

[1] For the purpose of this article, yellow maize also refers to those with orange kernels.

from records of travelers as early as the beginning of the nineteenth century (McCann, 2005). In other African countries, colored maize varieties were also the first to be introduced and cultivated. This was until white maize took over following its introduction and production in early twentieth century stimulated chiefly by the demand from the British starch industry and subsequently by the local market policy shifts against colored maize (Smale and Jayne 2004; Muzhingi *et al.*, 2008; De Groote *et al.,* 2010). South Africa is the principal African country that produces a significant amount of yellow maize, though still lower in quantity than its white maize production, to supply its relatively advanced livestock industry. Hence, South Africa is the only African country where yellow maize appears in production statistics (McCann, 2005).

In many African countries, the prevailing less preference for yellow maize is partly attributed to the stigma attached to it because it is predominantly used in food aid shipments during hunger periods, plus conventional thinking that considers yellow maize fit only for animals rather than human consumption (Tschirley and Santos, 1995; FAO and CIMMYT, 1997; Muzhingi *et al.*, 2008; De Groote and Kimenju, 2008; De Groote *et al.*, 2010). Yet, in some African countries like Angola where maize is less thoroughly promoted as a commercial crop, consumers still have no problem accepting yellow grained maize. In many areas in Africa smallholders still preserve seeds of early maturing and brightly colored flint and semi-flint garden maize (McCann, 2005).

How Yellow Maize Targeted Breeding of Ethiopia Started: A Flashback and More

The current dominance of white maize cultivation in Ethiopia appears to have come as a result of utilization of superior locally adaptable white kernelled East African and CIMMYT maize germplasm accessions for the development of improved white maize varieties (Benti *et al.*, 1993; Kebede *et al.*, 1993; Mosisa *et al.*, 2002). These varieties are now widely popular in the maize growing belts of Ethiopia.

As previously noted, colored maize (including yellow maize) have been in the hands of Ethiopian maize farmers for centuries. Around Bako, for instance, farmers' varieties called *Jirru*, *Burre* (mixture of different colors), and *Sefi* are cultivated. However, such local colored maize materials are very poor in their performance, and thus not preferred for commercial production. Even though maize breeding in Ethiopia began six decades ago with an emphasis on genotypes having white endosperm (Benti *et al.*, 1993), yellow maize targeted breeding has a very recent history – it began just six years ago. Previous to this, several yellow maize materials had been introduced and tested in an 'inadvertent' manner, only while introducing and evaluating maize materials for the purpose of identifying varieties with better agronomic performance and grain yield, most likely without taking heed of any advantage pertaining to grain color. In addition, the majority of these yellow maize materials were not attractive enough to catch the eyes of the breeders and make it through to official release. Most likely, the only commercially available improved yellow maize variety that can be cited as identified and officially released in such a process (in 2000 by the moisture stress maize research program) is Melkasa1. This maize variety is an extra early open-pollinated variety (OPV) having potential yield of 3.5–4.5 t ha^{-1} and is recommended for growing in the moisture stress prone areas of Ethiopia (Mandefro *et al.*, 2002). Melkasa1 was especially easily adopted in the Somali region where yellow maize consumption was already common. There were also other yellow maize varieties developed in the past, such as Alamura yellow and Bukuri (Dejene and Habtamu, 1993; Hussien and Kebede, 1993). However, these did not have much popularity and largely were not adopted by farmers. In any case, it can be generalized that the testing and eventual release of such yellow varieties, apart from their aim of contributing to food and nutritional security, were not the result of demands for yellow kernelled maize, nor were they promoted with the objective of exploiting the micro-nutritional benefits associated with the color of yellow maize.

Around 2004, increased expansion of commercial poultry farms instigated demand for improved yellow maize varieties with higher yield and stronger color intensity. This in turn gave birth to research specifically tuned to yellow maize germplasm enhancement as one of the objectives of the National Maize Research breeding programs. At that point, Melkasa1 was the best locally available improved yellow maize variety. However, it was unsatisfactory to meet the demand of the poultry industry due to its adaptation only to the low moisture stress areas and its lower yield potential. Demand from a few food processing industries (due to yellow maize being the commonly used major ingredient of corn flakes) can also be considered as a factor for pushing yellow maize research forward.

Though yellow maize has been bred under each of the major maize agro-ecologies of Ethiopia, much of the breeding has been under the mid-altitude sub-humid maize agro-ecology. This could be due mainly to the high potential of the area for maize production in order to offer an immediate answer to the demand of the emerging commercial livestock production and food/feed processing plants. Thus, this review is dominated by the report of yellow maize breeding of the mid-altitude sub-humid maize agro-ecology.

Major Activities and Accomplishments in Yellow Maize Breeding in Ethiopia since 2004

Field evaluation of locally available and exotic yellow maize germplasm composed of inbred lines, OPVs and hybrids has been vital in the germplasm enhancement effort of yellow maize. Thus, since the inception of the research program, numerous yellow maize materials, both locally developed and introduced, have been tested every year across locations with the objective of identifying varieties that are better performing or equivalent to the released white maize varieties in terms of yield, reaction to major diseases and other relevant agronomic traits. The research program has also been participating through conducting HarvestPlus[2] trials of yellow maize materials having improved pro-vitamin A content. The trials have been useful in identifying genotypes for direct release and/or use in further breeding activities; inbred line extraction and synthetic formation. Concurrently, yellow maize inbred line development and formation of different types of crosses and synthetics have been underway using introduced and/or local germplasm sources to generate experimental varieties for multi-location testing. Several maize materials with dual 'special' traits, namely yellow and quality protein, have also been developed.

At the outset, in the 2004 main-season, a small trial of a few yellow maize genotypes was conducted at Bako research station. Six open-pollinated yellow maize varieties (five exotic varieties and one farmers' variety called *Sefi*) were evaluated in the trial. Except for two of the entries, all varieties showed significantly less grain yield than the white maize commercial check (Gibe1). Concurrently, development of inbred lines begun from each of the five exotic OPVs. Advancement of selected lines continued through the main cropping seasons afterwards.

In the 2004/05 off-season, all yellow maize inbred lines available from the germplasm store of Bako National Maize and introduced from CIMMYT were planted at Bako research station. The objective was to promote any material deemed useful for further breeding improvement. Hence, lines that managed to grow well and set pollen and shoots/silks were used to generate single crosses.

In the main cropping season of 2005, two local sets and two introduced sets of trials were conducted at Bako. The trials composed of 55 hybrids (three-way and single crosses). Generally, thirteen entries showed good overall performances. One of the trial sets composed 19 yellow quality protein maize (QPM) single cross hybrids. In this trial, a single cross CML161/CML165 was found to be the best yielder giving 9.6 t ha^{-1}, while the check gave just 7.6 t ha^{-1}. This promising variety was selected for further testing across locations to confirm its performance in multi-environmental conditions. During the same season, a *per se* performance trial of some introduced CIMMYT flagship yellow lines including CML171, CML172, CML191, CML192, CML193, CML461 and CML165 was carried out to identify locally adapted lines for cross formation.

In 2006, four trials were econducted in which 107 entries were evaluated across 2–6 locations distributed in the mid-altitude maize agro-ecology (Bako, Hawassa, Jimma, Pawe, Adet, Fnote-Selam, and Arsi-Negele). No entry with better performance than the white commercial checks (BH540, BH541 and Gibe1) was observed. In one of the trials, an open-pollinated farmers' variety, *Jirru*, obtained from around Bako performed equivalent to the check in terms of yield, however, it was very late maturing and very tall, and thus susceptible to lodging.

The task of producing single crosses continued during the 2006 main cropping season and the succeeding off-season (2006/07) using the locally tested CIMMYT lines. By then, the research project was in a position to commence test cross formation using materials that were relatively well known, CML287 and S91SIY (a yellow OPV introduced and tested before 2004), as testers. Use of CML287 was, however, dropped at a later stage owing to its susceptibility to locally important foliar diseases observed while testing it in the subsequent seasons.

The main cropping season of 2007 hosted three local sets of yellow maize trials, a variety verification trial and another introduced trial (from CIMMYT-Mexico, fresh seeds of CML161 and CML165 were also introduced by this time). Under the locally organized trials, 44 single crosses were evaluated at two locations in the mid-altitude agro-ecology. None of the hybrids

[2] HarvestPlus is a collaborative organization of international research institutions and implementing agencies working together to breed and disseminate crops for better nutrition (www.HarvestPlus.org).

beat the best commercial white hybrid check (BH543). The introduced trial composed of 28 entries and was evaluated only at Bako. In this trial, the single cross CML161/CML165 gave 10.3 t ha^{-1}, significantly higher (α<0.05) than the best local check, BH543 (9.0 t ha^{-1}). In addition, another good performing hybrid (CML451/CML486)//CL02450=P24STEC1F16-1) was identified.

Based on the observation that the yellow single cross, CML161/CML165, had done well in a trial conducted in 2005, and additional information regarding its previous release in other countries, the hybrid was proposed for official release in 2007. To this end, a variety verification trial was conducted at three locations (Bako, Hawassa and Jimma) in the main-season of 2007. The hybrid did hold its promise as demonstrated by its yield advantage of 14.3% over BH540, and 19.1% over BHQP542 (Table 1). The only problem of the hybrid observed at Bako was some ear rot attack, perhaps due to the excessive rainfall and high humidity experienced during the season. However, even if this initially tempted the breeders to re-consider their proposition of the hybrid for release to the National Variety Release Committee (NVRC); agreement was finally reached, with the advice of the NVRC itself, to push the hybrid to its eventual release in 2008 under the name BHQPY545. The reasons included: firstly, the proportion of ear rot attacked ears was insignificant (only about 14% of the ears harvested on-station); secondly, the hybrid was reasonably productive as observed in many other trials conducted during the same and/or previous growing seasons; thirdly, there was no yellow maize hybrids available in the country for commercial production to meet the growing demand for yellow maize. This same hybrid is known to have wider adaptation and stable performance internationally as evidenced by its commercial production in several other Asian and Latin American countries (Prasanna *et al.*, 2001; Srinivasan *et al.,* 2004; Vasal *et al.*, 2006).

In the same season during which a verification trial was planted, a national variety trial (constituting both white and yellow maize varieties) was also carried out around Bako, Hawassa and Jimma, at 9 sites both on-station and farmers' fields in order to generate adequate data on the performance of the hybrid CML161/CML165. The single cross showed good across-location overall performance with better grain yield than the checks (BHQP542 and BH540) (Table 2).

By the year 2007, the research project had managed to identify several promising lines, OPVs, and single crosses (Table 3). Numerous experimental inbred lines had also been generated but their cross performances were yet to be evaluated. These materials were used in breeding activities in the 2007 main-season and resulted in the generation of numerous experimental three-way crosses, top and double-top crosses and single crosses through test and diallel crossing schemes. The hybrids generated were organized into different trials and tested across different locations in the 2008 main cropping season. In total, 84 hybrids

Table 1. Grain yield (t ha^{-1}) obtained in yellow QPM variety verification trial in 2007.

Entry	Bako			Hawassa		Jimma			Average
	On-station	On-farm (Anno)	On-farm (Shoboka)	On-station	On-farm	On-station	On-farm (Kersa)	On-farm (Nada)	
CML161/ CML165	9.1	5.6	5.9	9.5	8.1	8.7	5.9	6.1	7.4
BHQP542 (QPM check)	8.1	5.3	5.3	7.5	5.4	7.3	5.3	5.4	6.2
BH540 (non-QPM check)	7.8	5.3	4.9	8.1	8.8	6.3	4.9	5.4	6.4

QPM = quality protein maize.

Table 2. Result of multi-location evaluation of yellow maize varieties at nine sites in Ethiopia (National Variety Trial) in 2007†

Pedigree	Mean grain yield (t ha^{-1}) of each location									Across location result				
	Bako (on-station)	Hawassa (on-station)	Jimma (on-station)	Shoboka (West Shawa)	Anno1 (East Wellega)	Anno2 (East Wellega)	Hawassa (on-farm)	Jimma (on-farm-1)	Jimma (on-farm-2)	Grain yield (t ha^{-1})	Ear aspect (1–5)	GLS (1–5)	TLB (1–5)	Rust (1–5)
CML161/CML165	8.4	9.5	7.5	6.7	7.7	6.8	9.0	5.3	4.6	7.2	2.1	1.8	2.3	2.1
BHQP542 (QPM Check)	8.0	6.8	7.9	6.3	7.4	5.8	5.9	4.5	3.7	5.6	2.2	1.9	2.3	2.1
BH540 (Non-QPM check)	7.6	7.6	7.4	5.9	8.0	6.2	10.3	4.8	4.5	6.9	1.9	2.8	2.5	2.2
LSD (0.05)	1.7	2.2	2.3	1.6	1.8	1.3	2.8	0.8	1.0	0.4	0.2	0.2	0.2	0.2
CV (%)	10.3	12.7	15.2	12.0	12.0	9.9	15.0	9.2	11.6	15.3	15.4	20.1	15.3	18.3

† Data of white maize experimental entries not shown. LSD = least significant difference, CV = coefficient of variance, GLS = gray leaf spot, TLB = *turcicum* leaf blight, QPM = quality protein maize.

were tested under six trials over 1–2 locations at Bako and Hawassa. In all trials, no significantly superior performance of the entries over the checks (BH540 and BH543) was observed. However, about 20 of the hybrids looked promising showing comparable performances with the checks.

In addition to the locally generated set of trials, two trials having a total of 117 hybrids were introduced from CIMMYT-Mexico (HarvestPlus Project) and tested under local condition in 2008. In total, eight entries showed good grain yield performance but the yield levels were not statistically ($\alpha<0.05$) better than the best local check BHQPY545. Another yellow maize trial received from China was also planted during the same season at Bako. These genotypes were early in maturity but performed totally badly in other desired agronomic characters.

Several other notable yellow maize breeding activities were performed in 2008. Sixteen lines with improved pro-vitamin A contents were introduced from CIMMYT-Mexico and evaluated at Bako. Simultaneously, the lines with good performance were used for the formation of top crosses and three-way crosses with the available elite yellow maize populations and single crosses. Moreover, test cross formation was carried out using two tester OPVs (Across S0 345 and Across Synthetic 8928) and a single cross (CML451/CML486). Inbred lines were also extracted from various promising F_2 populations composed of elite CIMMYT lines. More interestingly, the first yellow maize synthetic formation was initiated using elite CIMMYT materials tested in the previous seasons. In addition, one open-pollinated yellow maize variety known as Melkasa7 was released for the moisture stressed maize growing areas by the low moisture stress breeding program in 2008. This variety had been shown to have a potential yield of 4.5–5.5 t ha^{-1}, which was a significant improvement over the previously released yellow OPV (Melkasa1) by the same breeding program.

The testcross outputs of 2008 were organized into four trials having 143 entries and tested across location in 2009 main cropping season. The performances of the testcrosses were not that attractive as compared to the check (BHQPY545). Two HarvestPlus trials were also introduced from CIMMYT together with their parental lines, and evaluated at Bako within the same season. Even if the entries did not surpass the check (BHQPY545) in terms of yield, the ear aspects of many of the entries in these trials were very impressive (i.e., in addition to their proven improved pro-vitamin A value). Selected hybrids and their parental lines will therefore be used in future breeding activities. Synthetic formation using these materials began in the 2010 main cropping season.

Table 3. Good performing yellow maize materials identified by 2007 in the mid-altitude zone in Ethiopia.

Material name	Type	QPM/ Non-QPM	Source
CML31	Inbred line	Non-QPM	CIMMYT
CML266	Inbred line	Non-QPM	CIMMYT
CML269	Inbred line	Non-QPM	CIMMYT
CML299	Inbred line	Non-QPM	CIMMYT
CML307	Inbred line	Non-QPM	CIMMYT
CML414	Inbred line	Non-QPM	CIMMYT
CML415	Inbred line	Non-QPM	CIMMYT
CML451	Inbred line	Non-QPM	CIMMYT
CML486	Inbred line	Non-QPM	CIMMYT
CML161	Inbred line	QPM	CIMMYT
CML165	Inbred line	QPM	CIMMYT
CML171	Inbred line	QPM	CIMMYT
CML172	Inbred line	QPM	CIMMYT
CML193	Inbred line	QPM	CIMMYT
CML194	Inbred line	QPM	CIMMYT
CML161/CML165	Single cross	QPM	CIMMYT
CML451/CML486	Single cross	Non-QPM	CIMMYT
CML299/CML307	Single cross	Non-QPM	CIMMYT
CML269/CML266	Single cross	Non-QPM	CIMMYT
Across SO 345	OPV	Non-QPM	CIMMYT
Across synthetic 8928	OPV	Non-QPM	CIMMYT

OPV = open-pollinated variety, QPM = quality protein maize.

Prospects of Yellow Maize Utility and Marketability in Ethiopia

Though yellow maize research was initiated in response to the demand from the small commercial poultry industry, it should be stressed that yellow maize is as suitable as white maize for human consumption. The significance of yellow maize as a human food becomes more relevant from the perspective of exploiting the crop as a cheap and sustainable source of vitamin A. The feasibility of maize pro-vitamin A biofortification and the associated positive and ultimate impact has been established by HarvestPlus (Nuss & Tanumihardjo, 2010). The currently ongoing endeavor is to develop and release high yielding vitamin A dense maize cultivars for vitamin A deficiency affected countries. Ethiopia will obviously benefit from such efforts as a country where vitamin A deficiency is a serious public health problem (Tsegaye *et al.*, 2010).

Elsewhere in Africa, the prevalent view that makes yellow maize inferior to white maize has been regarded as a possible barrier to the adoption of nutritionally improved yellow maize (De Groote and Kimenju, 2008). Such an obstacle does not seem to hamper the dissemination of yellow maize in Ethiopia, where both shipment of maize as food aid and its use as animal feed are negligible. However, the preference of the present-day Ethiopian maize farmers and consumers for yellow maize should be a subject of scientific assessment since white maize is currently dominating the country's maize fields and markets, and since good performing yellow hybrid maize have been introduced into commercial production just recently.

The recently released hybrid BHQPY545 is a very important product not only as animal feed, but also for direct human consumption and raw material in the food processing industries. Faster and wider promotion of this hybrid can be achieved through enlightenment of farmers and consumers on the two-fold benefit of the hybrid. The lesson learnt while undertaking demonstration and popularization of this hybrid, especially in the districts of East Wollega and West Shoa, can be indicative of the prospect of yellow maize acceptability among maize growing farmers. Views of the participating farmers were generally positive. The good appreciation of the taste, baking (as bread or *injera*), and flour qualities of the variety by the farmers hosting the demonstration trials can also be taken as a sign that Ethiopian farmers can easily accept yellow kernelled maize, as long as it satisfies their basic preferences.

A few commercial poultry producers and food and feed processing industries have started to use maize grain as a direct raw material (Diriba *et al.,* 2002). The seemingly inevitable increase in the industrial use of maize grain as raw material for processed food and feed will create increased demand for yellow maize. The national maize research project has made an effort to link such industries (especially the FAFA food processing company) with farmers through field days and workshops to try to create awareness and assurance among farmers on the availability of market for yellow maize grain. The farmers involved, with an offer of attractive price by the food processing company, have shown complete willingness to keep producing yellow maize.

In the introductory section, we indicated the worldwide benefit of yellow-grained maize particularly as animal feed. The advantage of the crop can potentially be put into good use in Ethiopia as well, bearing in mind the country's huge livestock population – the largest in Africa and only tenth in the world (MacDonald, 2009). In particular, the emerging commercial poultry production within the country offers an open opportunity for production and consumption of yellow maize. The ongoing effort by the government to encourage the large-scale commercial poultry industry, a system that has been largely based on small-scale rural production (MacDonald, 2009) further strengthens the prospect of local yellow maize utilization as animal feed.

Looking ahead into the future, there is ample opportunity for Ethiopia to become an exporter of maize, especially with improvement of the transportation and market infrastructure that creates easy and cheap outlets for the surplus maize produced by small scale farmers. Given the tiny international market for white maize compared to that of yellow maize which is by far larger (McCann, 2005), cultivation of yellow maize in Ethiopia can be advantageous since it can contribute to foreign currency generation.

Conclusions

Maize improvement research in Ethiopia has to date been focused mainly on serving the purpose of direct human consumption. This of course makes sense in view of the crop's importance as one of the strategic crops selected by Government to ensure food security in the country, as the crop is a basic staple for many people and has high inherent yield potential. But, the lesson learnt was that developments in the other sectors which use yellow maize can encourage additional research on yellow maize in the maize breeding program. This was why the effort of yellow maize breeding discussed in this paper was actually initiated. Although still more has to be done, it can be concluded that the yellow maize research in Ethiopia has already answered a demand for yellow maize that initially came from the poultry industry. Yet, new yellow maize varieties (both hybrids and OPVs) are needed, especially those improved with respect to their pro-vitamin A content, to improve public health through improved nutrition.

Finally, the undertaking of improved yellow maize variety development, together with the breeding program of QPM, can epitomize the prospect of diversification of research objectives in the national maize program by targeting goals beyond breeding efforts focusing merely on yield and related traits. This shows that there can and should still be the possibility of creating more room in the breeding program to accommodate any arising demand for maize varieties of particular traits, for example, specialty maize cultivars including pop corn, sweet corn and high oil containing maize.

A Way Forward for Yellow Maize Breeding in Ethiopia

Until the release of the first single cross hybrid for the mid-altitude maize agro-ecology, the main focus was to identify a genotype for immediate release so as to quickly meet the pressing demand for yellow maize. It took the project only four years to identify, adapt and finally release the yellow maize hybrid, BHQPY545. The search for a suitable third parent to generate a three-way cross version of the single cross is already under way, which will take care of the seed producers requirement for a high yielding seed parent. Had the project concentrated only on inbred line development, and cross/synthetic formation, it would have taken decades to come up with a usable variety. This affirms the importance of introducing international trials composed of varieties that are experimental and/or already released elsewhere in the world with similar agro-ecology for faster progress. Partnerships with institutes like CIMMYT and the International Institute of Tropical Agriculture (IITA) have been and will continue to be important in this regard. Introduction of exotic yellow maize germplasm from other countries like South Africa that have better experience in yellow maize breeding can also be useful.

The availability of a huge global market for yellow maize, its potential local use as feed, its natural capacity to serve as a cheap and sustainable source of vitamin A, and the presumed minimal negative opinion on yellow maize among Ethiopian farmers and consumers can all be considered as go ahead signals for yellow maize breeding in Ethiopia.

The breeding activity on yellow maize should continue in a more organized and structured manner. General combining ability (GCA) and specific combining ability (SCA) data obtained from the combining ability studies and information on heterotic group of CIMMYT lines should be wisely utilized so as to categorize these inbred lines accordingly. This way, synthetics of different heterotic groups can be formed from which inbred lines can be extracted. Inbred lines generated in this manner and properly selected for hybrid formation would make the breeding effort more fruitful and efficient through exploitation of heterosis.

What is more, in view of promoting yellow maize cultivars with better nutrition for human consumption, the project should consider ways of selecting those yellow maize materials with better pro-vitamin A content (especially HarvestPlus materials). In fact, the laboratory analyses requirement regarding measurement of pro-vitamin A levels in kernels can be expensive and demanding beyond the capacity of the project at this moment. Nonetheless, materials with dark yellow to deep orange colored kernels, (likely containing higher levels of pro-vitamin A), can be selected during evaluation, which is something that has not been practiced extensively to date. Future breeding efforts should also find ways of incorporating cheaper molecular tools to improve the local yellow maize germplasm in their pro-vitamin A content. The recent inauguration of the National Biotechnology Center creates a good opportunity to realize this vision but it is essential that there is a clear focus on the use of molecular tools to advance the breeding effort and efficiency. Human resource capacity building in the relevant field is also important to equip people in current advances in molecular breeding that can be interfaced with the conventional breeding program. This is particularly important for pro-vitamin A breeding which currently requires expensive and cumbersome phenotyping techniques.

Finally, taking the potential benefit of the yellow maize crop to fight vitamin A deficiency into account, each agro-ecology in Ethiopia should make its own effort to develop yellow maize germplasm adapted to its respective agro-ecology.

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Recent Advances in Breeding Maize for Enhanced Pro-Vitamin A Content

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Introduction

Several studies conducted for more than four decades have established that vitamin A deficiency is a serious public health problem in Ethiopia (Demissie *et al.,* 2009). It is estimated that more than 40% of preschool-aged children and 13% of pregnant women suffer from sub-clinical vitamin A deficiency in the country (WHO, 2009). This deficiency weakens children's immune system, predisposing them to several major infectious diseases such as anemia, diarrhea, measles, malaria and respiratory infections (Sommer and West, 1996; Shankar *et al.,* 1999; Villamor and Fawzi, 2000; West, 2000; West and Darnton-Hill, 2008). About 19% of child mortality from diarrhea and 24% child mortality from pneumonia in Ethiopia have been attributed to vitamin A deficiency (UNICEF, 2009). Vitamin A deficiency increases incidence of corneal blindness and contributes to poor growth and cognitive development in children (West and Darnton-Hill, 2008). This deficiency has also been associated with maternal death and poor pregnancy and lactation outcomes (Rice *et al.,* 2004; Black *et al.,* 2008). Thus, any effort directed to minimize vitamin A deficiency can improve the health and wellbeing of women and children. Meta-analysis of eight vitamin A supplementation trials in developing countries has clearly shown a 23% reduction in child mortality associated with diarrhea and measles (Beaton *et al.,* 1992).

The primary cause of vitamin A deficiency in Ethiopia and other countries in Africa is inadequate consumption of foods that are rich in vitamin A, including meat, egg yolks, whole milk and milk products, fish, cod liver oil, butter, papayas, mangos, pumpkins, carrots, orange sweet potatoes, spinach, kale, and Swiss chard (FMH-FHD, 2004; West and Darnton-Hill, 2008). The problem of vitamin A deficiency is exacerbated by over-dependence on cereal-based diets, which supply little or no vitamin A to meet the minimum daily requirement of the body (Haider and Demissie, 1996; Ruel, 2003; WHO/FAO, 2004). Millions of families in Ethiopia cannot usually afford animal products due to lack of income to purchase them (Demissie *et al.,* 2009). Fruits and vegetables are inaccessible to the vast majority of the people, and their availability depends on season and location (WHO, 2003). Other factors that contribute to higher risks of vitamin A deficiency among children include large family size, high maternal parity levels, low level of maternal education, low levels of awareness of the importance of vitamin A, and illnesses (Demissie *et al.,* 2009).

Periodic distribution of vitamin A supplements and food fortification with vitamin A have been used as primary vehicles to alleviate vitamin A deficiency and its disabling and potentially fatal health impact in Ethiopia (Taffesse and Fisseha, 1994; Kassaye *et al.,* 2001; FMH-FHD, 2004). Also, nutrition education and dietary diversification have been promoted to a limited extent to reduce vitamin A deficiency (Taffesse and Fisseha, 1994). Although vitamin A supplementation and food fortification have been used as quick and effective vehicles to reduce chronic vitamin A deficiencies, these approaches are usually considered unsustainable and inaccessible to the vast majority of people in developing countries due to economic, political, and logistical reasons (Welch and Graham, 2000). Supplementation is expensive and covers a limited number of children who are at risk, has high distribution cost, and requires maintenance of records for periodic dosing (Underwood and Arthur, 1996). Furthermore, excessive use of vitamin A supplements and fortified foods without close monitoring can cause toxicity and extra health problems (WHO/FAO, 2004).

Even though these intervention programs have been underway since 1989, (Taffesse and Fisseha, 1994; Kassaye *et al.,* 2001; FMH-FHD, 2004; Demissie *et al.,* 2009), the problem of vitamin A deficiency continues to be serious in Ethiopia. A recent nationwide study revealed that 38% of children 6 to 71 months of age still suffer from vitamin A deficiency (Demissie *et al.,* 2010). It is, thus, necessary to consider food-based approaches as a long term solution to combat vitamin A deficiency while intensifying the ongoing vitamin A supplementation and fortification programs. Enhancing the pro-vitamin A content of staple food crops like maize that are consumed in large quantities every day and used as the main component in most of the local weaning foods has been considered an important approach with good prospect of contributing to reductions in vitamin A deficiency (Bouis and Welch, 2010).

Targeting Maize for Improvement in Pro-Vitamin A Content

In recent years, efforts have been underway to improve the pro-vitamin A content in staple food crops to overcome vitamin A deficiency in areas with limited access to animal products, fruits and vegetables (Bouis and Welch, 2010). Maize is a staple food crop in Ethiopia and other countries in sub-Saharan Africa, providing more than 50% of the total calorie intake in Southern Africa and 30% in East Africa alone (McCann, 2005). Increasing the concentrations of pro-vitamin A in maize can, therefore, contribute to the reduction in vitamin A deficiency and improvement in the health status of people in sub-Saharan Africa. Yellow maize is an important grain crop that naturally accumulates a significant amount of carotenoids in its seed. It contains three carotenoids, namely β-carotene, β-cryptoxanthin and α-carotene, which are precursors for vitamin A. Maize is also a good source of lutein and zeaxanthin that have no vitamin A activity but are beneficial to human health (Krinsky *et al.,* 2003). The consumption of carotenoid-rich foods is associated with reduced risks of developing cancer (Gerster, 1993; Sies and Stahl, 1995; Agarwal and Rao, 2000) and cardiovascular diseases (Dagenais *et al.,* 2000; McDermott, 2000), enhanced immune responses (White *et al.,* 1988; Watzl *et al.,* 2003), improved vision and prevention of night blindness (Combs, 1992; Granado *et al.,* 2003; Olmedilla *et al.,* 2003) as well as maintenance of healthy skin, and gastrointestinal and respiratory systems (Bendich, 1993). Increased dietary intake of lutein and zeaxanthin has been associated with lowering the risk of cataracts, age related muscular degeneration and other degenerative diseases (McDermott, 2000; Mares *et al.,* 2006). Since commonly cultivated maize cultivars around the world contain little pro-vitamin A in their kernels (Harjes *et al.,* 2008), further increase in concentrations of pro-vitamin A carotenoids in maize endosperm using conventional breeding has been considered important.

Carotenoids in maize and other plants are synthesized via the carotenoid biosynthetic pathway. This pathway is responsible for the synthesis of an array of carotenoids classified as xanthophylls and carotenes (Vallabhaneni and Wurtzel, 2009; Farré *et al.,* 2010). The first reaction that provides substrates to the carotenoid biosynthetic pathway is catalyzed by an enzyme to produce a phytoene. Phytoene is then modified through a series of reactions catalyzed by different enzymes to produce the red colored carotenoid compound, lycopene. Lycopene forms two separate downstream branches called α and β branches (DellaPenna and Pogson, 2006). The two carotenoids, namely α-carotene and lutein, are synthesized in the α branch while β-carotene, β-cryptoxanthin and zeaxanthin are synthesized in the β branch. Among all carotenoids in maize, only β-carotene has full vitamin A activity due to its doubly ended β rings, while carotenoids that have only a single β ring, including α-carotene and β-cryptoxanthin, have half the vitamin A activity of β-carotene (Vallabhaneni and Wurtzel, 2009; Farré *et al.,* 2010). Consequently, breeding for increased pro-vitamin A content should involve increasing accumulation of total carotenoids that determine the amount of substrates siphoned to the downstream branches, as well as increasing the relative concentrations of α-carotene, β-carotene, and β-cryptoxanthin more than those of lutein and zeaxanthin in the biosynthetic pathway.

Assessment of the Genetic Potential to Breed for High Pro-Vitamin A Content

An essential first step in breeding yellow maize for enhanced carotenoid concentrations involves an assessment of the carotenoid diversity of adapted maize inbred lines. Trials were thus conducted (i) to explore the genetic variation in carotenoid concentrations among tropical-adapted yellow maize inbred lines, (ii) to determine consistency in expressions of carotenoid levels in different growing environments, and (iii) to assess the potential for concurrent improvement of the concentrations of different carotenoids. Seed samples of a large set of yellow endosperm maize inbred lines harvested from different trials grown in at least one location were analyzed for carotenoid content using high performance liquid chromatography (HPLC). Analyses of variance showed that carotenoid contents were not strongly affected by the differences in replications or locations (Menkir *et al.,* 2008). Significant differences were found among adapted yellow maize inbred lines in lutein, zeaxanthin, β-carotene, β-cryptoxanthin, α-carotene and total pro-vitamin A contents. Some inbred lines that exceeded the trial average by 60–260% in β-carotene and by 60–170% in pro-vitamin A were identified from these inbred trials. Other studies also found significant genetic variation in carotenoids in yellow maize lines and hybrids adapted to temperate environments (Brunson and Quackenbush, 1962; Grogan *et al.,* 1963; Kurilich and Juvik, 1999; Quackenbush *et al.,* 1966; Weber, 1987).

Principal component analysis of the carotenoid composition of tropical-adapted yellow endosperm inbred lines evaluated in four independent trials identified some lines with higher levels of all carotenoids formed across the two major branches of the carotenoid biosynthetic pathway, and other lines having higher levels of specific carotenoids formed under a single major branch of the carotenoid biosynthetic pathway (Menkir *et al.,* 2008). These results suggest that selection of parental lines with diverse carotenoid profiles for crossing may permit accumulation of higher levels of pro-vitamin A carotenoids in tropical maize. To confirm consistency in expression of carotenoid concentrations in adapted maize, 22 inbred lines with contrasting carotenoid content selected from various trials and 20 hybrids formed from selected yellow endosperm inbred lines were evaluated at four and two environments, respectively. Assessment of consistency of the relative ranking of inbred mean carotenoid content across environments showed significant ($p<0.05$ to $p<0.001$) coefficients of concordance (Kendall, 1962) varying from W = 0.71 for β-cryptoxanthin to W = 0.96 for α-carotene in the inbred trial and from W = 0.78 for lutein to W = 0.90 for zeaxanthin in the hybrid trial. The significant and positive coefficients of concordance observed in each trial suggest that changes in the relative ranking of mean carotenoid content of the lines or hybrids were not substantial across different growing environments. Correlation analyses in several trials involving a large number of diverse inbred lines revealed that relationships among carotenoids were either significant and positive or not significant and small, suggesting that it should be feasible to improve the levels of multiple carotenoids simultaneously (Menkir *et al.,* 2008).

Breeding for Increased Pro-Vitamin A Content and Progress Achieved

Our general breeding approach has focused on exploiting existing and induced genetic variation to increase concentrations of pro-vitamin A carotenoids in inbred lines and selected open-pollinated varieties (OPVs) to develop new maize cultivars that can contribute to improved nutrition, health, and quality of life of people in Africa. To attain this, standard maize breeding procedures have been used to improve levels of pro-vitamin A carotenoids in maize. Adapted maize inbred lines selected for high ß-carotene and pro-vitamin A content have been used to generate several bi-parental crosses. Additionally, adapted maize inbred lines endowed with complementary levels of pro-vitamin A carotenoids have been selected and used to generate several bi-parental crosses that may allow manipulation of flux at the various stages of the carotenoid biosynthetic pathway to develop new inbred lines with much higher levels of pro-vitamin A content. The standard pedigree breeding procedure has been used to develop new inbred lines from the two groups of bi-parental crosses. At each stage of inbreeding, selection has been based on intensity of kernel color, flint or semi-flint type of kernel texture, synchrony between pollen shed and silking, resistance to the major prevalent foliar diseases, and other desirable agronomic traits. Furthermore, 15 inbred lines introduced from the University of Illinois as potential sources of high ß-carotene content were crossed to adapted tropical and sub-tropical maize inbred lines selected for high pro-vitamin A content. The resulting F_1s were crossed back to the respective adapted parent to develop the first backcross populations, which were self-pollinated to generate F_2 seeds. Ears that combined bright yellow to orange kernel color with flint and semi-flint endosperm texture were selected from among the self-pollinated plants harvested from each backcross population and threshed to form balanced backcross bulk seeds. The backcross bulk seeds have been sources of new generations of inbred lines that combine high levels of pro-vitamin A with desirable adaptive traits.

At the S_4 or S_5 stages of inbreeding, selected inbred lines with desirable agronomic traits, resistance to lodging and foliar diseases, low ear placement and good synchrony between pollen shed and silking derived from bi-parental crosses and backcross populations were subjected to carotenoid analysis at Iowa State University, University of Wisconsin and International Institute of Tropical Agriculture (IITA) laboratories. As shown in Fig. 1, large differences in both ß-carotene and pro-vitamin A concentrations were detected among these lines. Most of the lines with high ß-carotene and pro-vitamin A concentrations were derived from backcross populations containing temperate germplasm as donors of high ß-carotene (Fig. 1). Among the best 74 inbred lines having pro-vitamin A content varying from 8 to 21 $\mu g\ g^{-1}$ and ß-carotene content varying from 3 to 20 $\mu g\ g^{-1}$, 71 were derived from backcrosses and 3 were derived from bi-parental crosses of adapted inbred lines. So far we have identified 21 promising inbred lines with 5–20 $\mu g\ g^{-1}$ ß-carotene and 10–21 $\mu g\ g^{-1}$ pro-vitamin A for use as parents of hybrids, synthetics and pedigree populations. As the HarvestPlus challenge program has set the breeding target for pro-vitamin A concentration for maize at 15 $\mu g\ g^{-1}$ to have significant nutritional impact on humans (HavestPlus, 2011), some inbred lines that accumulate up to 15 $\mu g\ g^{-1}$ or higher levels of pro-vitamin A in their endosperm have been identified in trials conducted at both CIMMYT and IITA. The potential contributions of these inbred lines to pro-vitamin A concentrations in hybrids is currently being tested in multiple locations.

The existing adapted and new maize inbred lines selected for intermediate levels (≥7.5 µg g^{-1}) of pro-vitamin A have also been used to form hybrids and synthetics for quick delivery of products for extensive testing and release. Several hybrids formed from such promising inbred lines have been tested in different trials in multiple locations for agronomic performance and carotenoid composition. Seed samples harvested from these trials have been subjected to carotenoid analysis in different laboratories. As shown in Fig. 2, marked differences in both ß-carotene and pro-vitamin A content were found among hybrids. Thirty-one hybrids having pro-vitamin A concentrations varying from 7.7 to 9.8 µg g^{-1} in their grain were formed from crosses between adapted and new inbred lines. These hybrids had higher levels of pro-vitamin A and ß-carotene in comparison to the commercial yellow endosperm maize hybrids used as checks (Fig. 2). Some of these hybrids were also found to be as high yielding as the yellow endosperm commercial hybrid check and had desirable agronomic traits (data not shown). In several trials that were conducted in multiple locations in Zambia and Zimbabwe, several promising three-way cross hybrids with pro-vitamin A concentrations of 6 to 8 µg g^{-1} have been identified and are currently being evaluated in national performance trials as part of the pre-release requirements in Zambia.

OPVs are the predominant cultivar types grown by farmers in West and Central Africa. The development and dissemination of synthetics with high pro-vitamin

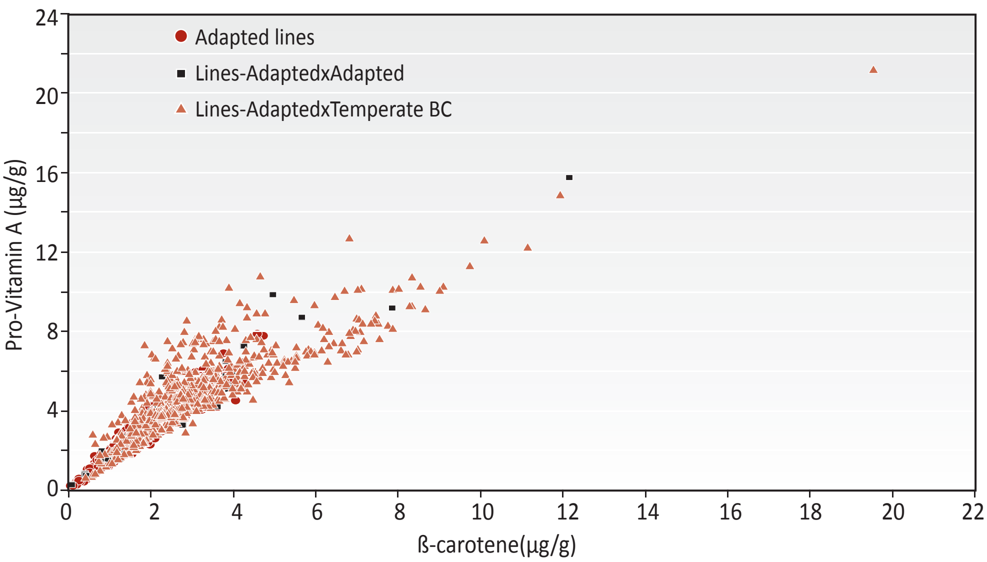

Figure 1. ß-carotene and pro-vitamin A content of selected adapted inbred lines as well as S_4 and S_5 lines derived from bi-parental crosses and backcross population analyzed in different laboratories.

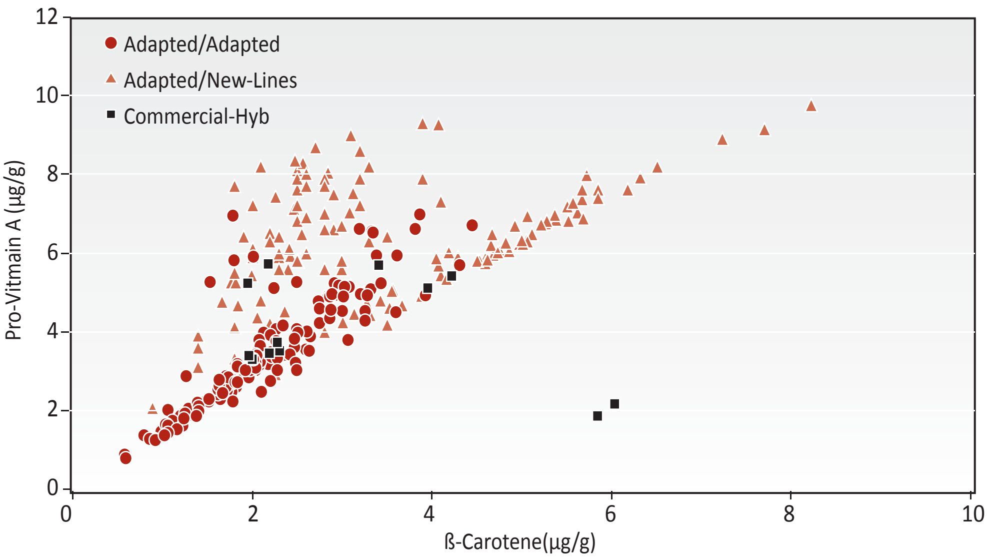

Figure 2. ß-carotene and pro-vitamin A content of hybrid formed from crosses of adapted and new inbred lines evaluated at multiple locations in different trials from 2005 to 2009.

A content can thus contribute to improved nutritional status and health of farming communities in the sub-region. Ten synthetics each formed from eight adapted maize inbred lines with 5–8 μg g^{-1} of pro-vitamin A were evaluated in multiple locations in 2009. As shown in Table 1, the difference among synthetics and checks was significant for concentrations of ß-carotene and pro-vitamin A as well as agronomic traits. The variety × location interaction mean squares were significant for almost all agronomic traits but not for pro-vitamin A and ß-carotene concentrations. The synthetics had more pro-vitamin A and ß-carotene concentrations in comparison with an orange endosperm OPV and a commercial hybrid used as checks (Table 1). These synthetics were found to be as high yielding as the OPV check and also had desirable agronomic traits. Several synthetics developed at CIMMYT using inbred lines selected for high pro-vitamin A concentrations are currently being tested in multiple locations.

Desirable sources of pro-vitamin A carotenoids were also crossed to broadly adapted varieties in Africa, namely Obatanpa, ZM521, and SAM4, to develop new versions of these varieties with high pro-vitamin A content. The resulting crosses have been subjected to S_1 recurrent selection at CIMMYT to continually accumulate and increase the frequency of favorable pro-vitamin A alleles while maintaining or improving agronomic performance in these populations. In each selection cycle, the best S_1 lines with desirable agronomic traits and higher levels of pro-vitamin A content were selected and inter-crossed to form the new cycle of selection. These populations have been subjected to three cycles of recurrent selection for increased pro-vitamin A concentrations. A trial consisting of the original cross and advanced cycles of selection of each of the three populations was evaluated for agronomic performance at more than 10 sites and for pro-vitamin A concentrations at three sites. Results of analysis of grain samples harvested from hand-pollinated ears at the three sites in 3 independent laboratories showed a realized gain of 0.906 μg g^{-1} pro-vitamin A per selection cycle in the three populations. The attainment of significant gains from S_1 recurrent selection across sites and laboratories provides evidence that genotype effects of selection were more important than the genotype × site and genotype × laboratory interaction effects.

Harnessing Selectable Molecular Markers for Increasing Pro-Vitamin A

Effective, reliable, inexpensive and rapid screening techniques are indispensable prerequisites to breed maize for high pro-vitamin A content. As measurement of carotenoids in maize with HPLC is relatively tedious, expensive, and time-consuming, this method is inappropriate for rapid and routine selection from among a large number of single plants or lines derived

Table 1. Mean pro-vitamin A and ß-carotene of hybrids obtained from Saminaka and Zaria and agronomic traits obtained from Ikenne, Saminaka and Zaria in 2009.

Hybrids	Pro-vitamin A (μg g^{-1})	ß-carotene (μg g^{-1})	Grain yield (t ha^{-1})	Anthesis (days)	Plant height (cm)	Plant aspect (1–5)†	Ear aspect (1–5)††
PVASYN8	6.6	3.7	4.5	57	190	2.2	2.6
PVASYN3	6.5	3.8	5.0	57	202	2.1	2.6
PVASYN6	6.2	3.2	4.4	58	190	2.3	2.7
PVASYN2	6.2	3.4	4.9	57	198	2.3	2.6
PVASYN9	6.2	3.4	4.0	58	195	2.3	2.6
PVASYN10	6.2	3.5	4.5	57	191	2.1	2.5
PVASYN5	6.0	3.3	4.3	57	192	2.6	2.8
PVASYN1	5.9	3.1	4.5	57	192	2.0	2.8
PVASYN4	5.8	3.3	5.0	57	188	1.9	2.9
PVASYN7	5.7	2.9	4.0	58	194	2.5	2.7
Oba Super II (Hybrid check)	4.9	2.7	5.3	58	192	2.5	2.5
P66SR/SUWAN1-SRC1*2 (OPV check)	4.3	2.3	4.6	55	190	2.7	2.8
Mean	4.7	2.7	5.5	57	193	2.2	2.5
S.E.	0.5	0.3	0.4	0.6	5.5	0.2	0.2
CV	17	18	16	3	5	17	16
Variety	***	***	***	***	***	***	***
Variety × location	ns	ns	*	ns	***	*	*

† A scale of 1 to 5, where 1 = excellent plant type with good agronomic traits and 5 = poor plant type with poor agronomic traits,
††A scale of 1–5, where 1 = excellent ear aspect and 5 = poor ear aspect, S.E. = standard error, CV = coefficient of variance,
ns = not significant, *** = significant at P ≤ 0.001, * = significant at P ≤ 0.05.

from several segregating populations (Pfeiffer and McClafferty, 2007). The poor correlation between endosperm color and pro-vitamin A carotenoid content also renders kernel color-based visual selection unreliable (Harjes *et al.,* 2008; Mishra and Singh, 2010). Fueled by the need for rapid and inexpensive tools to screen maize for pro-vitamin A, recent genetic studies identified two key genes regulating critical steps in carotenoid biosynthesis and developed PCR-based functional markers that directly detect alleles (LCYE, HYD3, HYD4, HYD5, HYD6, CYP97A, and CTP97C) representing significant polymorphic sites in the two genes (Harjes *et al.,* 2008; Yan *et al.,* 2010). Use of these markers is much cheaper than HPLC determination and has begun to speed up the selection process by allowing selection for optimal allelic combinations at the seed or seedling stage, instead of waiting for assessment of endosperm carotenoid composition after harvest. Since the selectable markers associated with the two genes were developed based on a set of sequences of limited inbred lines of mainly temperate origin, a test of their effectiveness in detecting polymorphism across diverse genetic backgrounds was conducted before their wider use in routine breeding for pro-vitamin A content (manuscript in preparation).

Several crosses with diverse genetic backgrounds, including seven segregating for favorable and unfavorable alleles of both genes, were developed at CIMMYT to validate the effectiveness of these markers for selection in tropical and sub-tropical adapted germplasm. Seeds of 400 plants derived from each population were analyzed for carotenoid composition and genotyped using markers linked to the most important alleles of the two key genes to determine their effect on pro-vitamin A content. The results of analysis of the nine genotypic classes in the six crosses showed that these alleles had strong effects, ranging from 43% to 258% increase in pro-vitamin A concentration in all crosses. These markers are currently being used at CIMMYT to enrich pro-vitamin A in tropical and sub-tropical maize. The functional markers developed for the alleles of the two key genes are also currently being validated at IITA using diverse inbred lines with contrasting pro-vitamin A content before their use to breed maize for high pro-vitamin A content.

Summary

CIMMYT and IITA are committed to breeding maize varieties and hybrids with enhanced levels of pro-vitamin A to contribute to improved nutrition, health, and quality of life of the people in rural areas. Several studies conducted in different locations have clearly demonstrated the presence of a considerable amount of genetic variability in concentrations of pro-vitamin A carotenoids within adapted and exotic maize germplasm that can be exploited to enrich pro-vitamin A content without adversely affecting its productivity. Several trials conducted in multiple locations over seasons also identified some maize inbred lines containing high levels of pro-vitamin A, which were consistently maintained in different test environments. Some adapted maize inbred lines with intermediate pro-vitamin A levels (≥7.5 µg g^{-1}) selected from different trials have been used for developing bi-parental crosses and backcross populations that contain temperate germplasm as sources of high ß-carotene. The resulting breeding populations have been sources of new maize inbred lines with pro-vitamin A content varying from 8 to 21 µg g^{-1} and ß-carotene content varying from 3 to 20 µg g^{-1}. Some of the adapted and new maize inbred lines have formed hybrids containing pro-vitamin A content varying from 7.7 to 9.8 µg g^{-1} in their grain while maintaining high yield potential and desirable agronomic traits. Results of studies also demonstrated that pro-vitamin A enriched OPVs can be developed using inbred lines selected for high pro-vitamin A as parents and S_1 recurrent selection in broad-based populations. Prospects are very good for increasing the concentrations of pro-vitamin A carotenoids in maize inbred lines using conventional and molecular tools to develop maize hybrids with levels of pro-vitamin A approaching 15 µg g^{-1}.

Acknowledgements

The authors express their appreciation to Dr. T. Rocheford (Purdue University) for providing temperate inbred lines that have been invaluable sources of high ß-carotene to breed tropical maize for high pro-vitmain A content. We thank Dr. W. White and Dr. S. Tanumihardjo for conducting carotenoid analysis. This breeding program has been financed by the HarvetPlus Challenge Program of the Consultative Group on International Agricultural Research (CGIAR). The authors are grateful to all staff members that participated during planting, data recording, harvesting and management of the trials at the various locations.

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Breeding Maize for Food-Feed Traits in Ethiopia

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Introduction

Small-holder mixed farming is the dominant mode of agriculture in Ethiopia. Crop production and livestock husbandry are practiced under the same management unit in the highland and mid-altitude areas. The system is mutually dependent: livestock greatly influence food production through draft power, cash availability and provision of plant nutrients from animal manure while crop residue plays a crucial role in livestock nutrition (Adugna *et al.,* 1999). The use of maize residues as feed for livestock is expected to increase further as more grazing land is put under cultivation due to the increasing human population density (Renard, 1997).

Maize is one of the most important cereal crops grown in Ethiopia and predominantly used for human consumption. In the mixed farming system, the residue constitutes the major diet for livestock particularly in the dry seasons (Adugna *et al.,* 1998, 1999; Diriba *et al.,* 2002). Maize is also used as fodder at the green stage. Until recently, maize improvement programs have been mainly focused on improvement of grain yield and related traits. Research in this regard, has resulted in noticeable success and thus provided a number of improved maize varieties for commercial production.

Before 2005, animal nutritionists were trying to assess released maize varieties mainly for their suitability to silage preparation and green fodder. Some studies were also conducted to observe genotypic differences for stover feed quality traits among commercial maize varieties. Most authors reported the existence of differences among the treatment varieties with respect to stover yield and most stover feed quality traits (Adugna *et al.,* 1998, 1999; Diriba *et al.,* 2002). However, no targeted breeding work was carried out to exploit the existing varietal differences for further improvement of the traits.

A systematic genetic study and breeding effort, for simultaneous improvement of food and feed traits, began following the launching of a BMZ (Bundesministerium Fur Wirtschaftliche Zusammenarbeit–German Federal Ministry for Economic Cooperation and Development) funded project coordinated by CIMMYT/ILRI (International Livestock Research Institute) in East Africa in 2005. During the project period, a number of maize genotypes were evaluated for both grain yield and stover feed quality and quantity traits in Ethiopia. The objective of this paper is, therefore, to review experiences and findings from breeding maize for food-feed traits in the last decade and indicate the future direction for simultaneous improvement of food and feed traits of maize.

Evaluation of Maize Varieties for Food-Feed Traits

Two major activities were carried out. The first was evaluation of already released and pipeline maize varieties for stover feed quality traits with the objective of assessing the level of genotypic differences among released and pipeline maize varieties in Ethiopia. The second was aimed at assessing the varietal differences for food-feed traits among a relatively larger number of experimental varieties. All agronomic practices during the field evaluations followed the existing recommendation for each specific location.

Evaluation of released and pipeline maize varieties

Sixteen released and pipeline maize varieties were evaluated at Bako Agricultural Research Center: on-station and on-farm. At grain harvest stage, sample plants were taken randomly from all plots and chopped manually to get homogeneous sub-samples required for laboratory analysis. Stover feed quality analysis of the samples was done at the ILRI-Addis Ababa nutrition laboratory. The results showed significant differences among the genotypes with regard to organic matter (OM), acid detergent fiber (ADF), true *in vitro* organic matter digestibility (TIVOMD) and neutral detergent fiber digestibility (NDFD) for the on-farm trial (Table 1). Genotype effect was also significant for stover yield, grain yield, dry matter (DM), and ADF in the on-station trial. In the combined analysis, genotypes showed significant difference for ADF. Location and genotype by location effect was not significantly different indicating the stability of ADF across different management conditions.

In the on-farm trial, the hybrid variety FH-625-259/F7215//142-l-e showed maximum value for OM and ADF while the highest value for digestibility; TIVOMD

(67.7%) and NDFD (55.1%) was observed for the hybrid CML216/A7062//CML197. Due to the fact that FH-625-259/F-7215//142-l-e had the highest percentage of ADF (51%), it was also the least digestible of all the genotypes included in this experiment (63.1%). It had the maximum value for lignin and stover yield in the on-station trial. It was also among the top grain yielding genotypes pointing to the possibility of getting high grain yield and stover yield simultaneously.

On the other hand, the quality protein maize (QPM) hybrid variety, BHQP542, included in the trial showed low values for stover yield, grain yield, DM and ADF. The lowest grain and stover yields observed for BHQP542 were mainly associated with its relatively earliness in maturity compared to the other treatment varieties. The contribution of a relatively longer growing duration on plant dry matter accumulation should be considered to prevent drawing an erroneous conclusion about yield potential of the QPM variety. There are a number of QPM varieties with comparable and even higher yield potential compared with similar non-QPM varieties. Some animal nutritionists have also speculated on the the stover feed quality of QPM varieties arguing that the increased protein quality in grain of QPM varieties could be at the expense of the decreased stover quality. However, total protein quantity of maize grain was almost similar for QPM and non-QPM varieties.

In QPM varieties, the most abundant proteins in the grain endosperm (zeins) which are poor in lysine and tryptophan are decreased and non-zein proteins that naturally contain higher levels of lysine and tryptophan are proportionally increased (Gibbon and Larkins, 2005). Therefore, the process of converting a maize variety to QPM only occurs in grain endosperm and it has nothing to do with stover or other plant parts.

Evaluation of experimental hybrids

A total of 97 experimental hybrids were evaluated for both yield (grain and stover) and stover feed quality traits from 2006 to 2008 (Table 2). In 2006, two highland maize trials consisting of 12 and 22 hybrids were planted and evaluated at three and two locations, respectively. The trial with 12 entries was evaluated at Ambo, Kulumsa and Holetta while the performance of the trial with 22 entries was assessed at Ambo and Bako. In addition, a trial consisting of 63 hybrids was evaluated at Bako, Hawassa and Jimma, mid-altitude sub-humid maize agro-ecology, for food and feed traits, in 2008. In all cases, there were highly significant differences between hybrids for grain and stover yields and stover feed quality traits (data not shown).

Even though the genotypes were initially developed mainly for grain yield, the areas observed in these studies indicated the existence of genotypic variation

Table 1. Mean grain yield and stover feed quality traits for released and pipeline maize varieties evaluated at Bako: on-farm and on-station in 2006.

	On-farm				On-station						Combined
Pedigree	OM	ADF	TIVOMD	NDFD	SY	GY	DM	ADF	Lignin	DSY	ADF
CML216/A7062//CML197	92.2	50.1	67.7	55.1	7.1	7.3	91.7	50.2	6.2	5.0	50.2
CML216/F7215//144-7-b	92.4	47.9	66.5	52.8	7.9	8.9	91.5	52.0	6.5	5.4	50.0
A7032/G7462//144-7-b	92.6	49.8	65.1	51.5	8.8	11.8	91.6	52.5	6.7	5.9	51.1
FH-625-259/F-7215//144-7-b	92.0	50.1	63.3	50.0	8.4	9.1	91.6	52.2	6.2	5.8	51.2
CML254/SC-22//144-7-b	91.7	50.0	66.9	53.8	9.9	11.4	91.4	50.8	6.3	6.7	50.4
X12646W1-2-1/CML197	91.7	50.3	67.0	54.1	7.3	8.7	91.8	53.1	6.1	5.0	51.7
CML146/F7215//144-7-b	91.9	48.0	65.5	51.6	8.9	10.3	91.6	50.2	6.5	6.0	49.1
SC22/124-b(109)//144-7-b	92.0	47.4	67.0	53.1	8.3	10.4	91.6	51.5	6.3	5.6	49.4
FH-625-259/F7215//142-l-e	94.0	51.0	63.1	48.7	10.4	11.6	91.4	52.2	7.2	6.9	51.6
CML144/F7215//142-l-e	93.1	48.3	63.1	47.4	8.3	9.4	91.7	49.5	6.2	5.7	48.9
BH660	92.2	49.7	65.2	51.6	8.3	8.9	91.6	52.5	6.2	5.7	51.1
BH540	91.1	49.3	65.1	52.4	6.5	8.8	91.9	51.5	6.9	4.3	50.4
BH541	92.1	49.8	65.7	53.9	6.8	7.7	91.2	49.2	5.5	4.9	49.5
BHQP542	91.7	44.4	63.8	50.0	6.5	6.9	91.2	45.7	6.0	4.4	45.1
Kuleni	91.5	46.4	65.5	51.7	6.8	7.4	91.8	49.2	6.1	4.7	47.8
Gibe comp1	90.8	47.8	63.7	50.8	7.2	7.4	91.4	47.6	5.9	4.9	48.2
Mean	92.1	48.8	65.3	51.8	8.4	9.1	91.6	50.6	6.3	5.7	49.7
Maximum	94.0	51.0	67.7	55.1	10.4	11.8	91.9	53.1	7.2	6.9	51.7
Minimum	90.8	44.4	-63.1	47.4	6.5	6.9	91.2	45.7	5.5	4.3	45.1
Range	3.1	6.6	4.6	7.6	11.4	4.9	0.7	7.3	1.7	7.4	6.6
F-test	*	*	*	**	**	**	*	**	**	**	**

* = statistically significant at P ≤ 0.05, ** = statistically significant at P ≤ 0.01, OM = organic matter, ADF = acid detergent fiber, TIVOMD = true in vitro organic matter digestibility, NDFD = neutral detergent fiber digestibility, SY = stover yield, GY = grain yield, DSY = dry stover yield, DM = dry matter.

among experimental hybrids for both food and feed traits suggesting a higher degree of success if targeted breeding is formulated to identify maize varieties that may fit into the mixed crop–livestock farming system where crop residue plays a vital role in animal nutrition.

Evaluation of Maize Inbred Lines for Stover Feed Quality Traits

The determination of variability among maize inbred lines is a key step towards the development of maize varieties for any trait of interest. To this end, 247 inbred lines having good performance for grain yield and other important agronomic traits were obtained from Bako (100 inbred lines) and Ambo (147 inbred lines) maize breeding programs. In 2005, these inbred lines were planted in un-replicated trials in their respective areas of adaptation. After harvest, stover samples of all the inbred lines from both sites were taken and analyzed for some common stover feed quality traits. Analytical services were provided by ILRI-Addis Ababa, Ethiopia. For sample preparation and stover feed quality analysis, the standard procedures of sampling and analysis were used (Van Soest, 1994).

The stover quality parameters ADF, TIVOMD, NDFD, dry matter intake (DMI, g kg^{-1} W 0.75) and digestible organic matter intake (DOMI, g kg^{-1} W 0.75) were determined. Values for ADF, TIVOMD, NDFD, DMI and DOMI ranged from 30–45%, 67–83%, 45–70%, 42–68 g kg^{-1} and 34–46 g kg^{-1} among the 147 highland inbred lines and 31–51%, 62–80%, 35–72%, 42–68 g kg^{-1} and 15–36 g kg^{-1} for the mid-altitude inbred lines, respectively. Inbred lines from both agro-ecologies were similar in value ranges for all quality parameters; and the ranges were also quite wide. The wide ranges observed for feed the feed quality traits were clear indications of existence of genotypic difference among the inbred lines of both agro-ecological zones for feed quality traits. The result clearly indicated the existence of genetic variability among maize inbred lines for stover feed quality traits.

Taking all the quality parameters into account, 41 inbred lines from the mid-altitude group were selected and grouped into three levels of feed trait quality performance: top (14 inbred lines), average (13 inbred lines) and poor (13 inbred lines). Likewise, 60 inbred lines from the highland group were also categorized into the three trait quality performance groups; each group consisting of 20 inbred lines. Inbred lines from the two extreme groups (top and poor) were used in crossing in a genetic study of stover feed quality traits and their relationship with grain yield and related traits was studied. The experiments were conducted in the mid-altitude sub-humid zone in 2008 using 16 inbred lines and their 60 hybrid cross combinations. The summary of the findings for the genetic study is presented later in this paper. The 16 inbred lines were evaluated in replicated trials across three locations for grain yield, other agronomic traits, and feed quality and quantity traits. The inbred lines showed significant differences ($P \leq 0.05$; $P \leq 0.01$) for grain yield, harvest index (HI), leaf to stem ratio (LSR), N, NDF, metabolizable energy (ME) and IVOMD (Table 3) confirming the result obtained in un-replicated trials in 2005 discussed above. The existence of genotypic variability among the inbred lines is particularly

Table 2. Trial name, number of genotypes evaluated, number of locations and the agro-ecology where the trials were evaluated for grain yield and stover feed quality traits.

Trial name	Number of genotypes	Number of locations	Agro-ecology	Range GY (t ha^{-1})	IVOMD (%)
AMB06NVT	12	3	Highland	7.9–10.3	61.2–68.0
AMB06TW	22	2	Highland	NS	NS
PVT2S	63	3	Mid-altitude sub-humid	7.1–11.8	53.0–62.3

GY= grain yield, IVOMD = in vitro organic matter digestibility, NS = not significant.

Table 3. Mean, minimum, maximum, F-test and coefficient of variance (CV) for grain yield (GY), agronomic traits and feed quality traits of 16 inbred lines evaluated at Bako, Hawassa and Jimma in 2008.

	GY (t ha^{-1})	HI (%)	LSR	N (%)	NDF (%)	ME (%)	IVOMD (%)
Mean	4.5	38.4	0.9	1.0	78.9	8.9	60.0
Minimum	2.2	28.7	0.6	0.8	74.9	8.26	55.89
Maximum	7.4	46.1	1.4	1.3	81.4	10.0	67.0
F-test	*	*	**	**	**	**	**
CV	20.5	7.1	12.0	7.8	1.6	2.7	2.7

HI = harvest index, LSR = leaf to stem ratio, N = nitrogen, NDF = neutral detergent fiber, ME = metabolizable energy, IVOMD = in vitro organic matter digestibility, CV = coefficient of variance, * = statistically significant at $P \leq 0.05$, ** = statistically significant at $P \leq 0.01$.

interesting in that dual purpose varieties could be developed by combining inbred lines having good *per se* and cross performance. Unfortunately, the concurrent evaluation of inbred lines from the highland group was not successful due to problems associated with poor plant establishment and seed set of the inbred parents during cross formation.

Genetic Study

Sixteen inbred lines adapted to the mid-altitude agro-ecology were used to study heterosis and combining ability of parents and correlation among traits in hybrids. The female and male inbred lines were composed of inbred lines with top and poor stover quality based on the previous years' stover quality analysis result. The 16 inbred lines (10 female and 6 male inbred parents) produced 60 single cross hybrids in a line by tester crossing procedure. Crossing was made in such a way that poor by poor, poor by top and top by top single crosses are generated. The resulting crosses and parental inbred lines were evaluated in separate trials in three locations in the mid-altitude sub-humid agro-ecology, namely Bako, Jimma and Hawassa Agricultural Research Centers, for grain yield and other important agronomic traits. In addition, data for stover yield and feed quality traits were generated from stover samples prepared following standard procedures. Stover samples were analyzed at the ILRI-Hyderabad animal nutrition laboratory in India. Using data generated in the field and laboratory, heterosis and combining ability of inbred lines and the relationship existing among different traits were determined.

Heterosis and combining ability studies of feed traits

Heterosis

Mid and high parent heterosis was positive and highly significant for grain and stover yields (Table 4). That means hybrids had higher grain yield as compared to the average yield of their respective parents and the higher-yielding parents. This is a desirable expression of heterosis in that these traits can be improved by hybridization, and the improvement programs should opt for hybrid breeding to exploit heterosis for the trait. On the other hand, undesirable heterosis was observed for most of the stover feed quality traits. Up to 40% reduction from the high parent value for nitrogen in stover and 13% for metabolizable energy and digestibility relative to the high parent values was observed. In this case, hybrids showed lower nitrogen content in stover and lower metabolizable energy and digestibility relative to their corresponding average and higher parental values. Nitrogen in stover could, however, be simply increased through the application of nitrogen fertilizer in soil to the level that is economically feasible (Blummel *et al*., 2007; Mosisa *et al*., 2007). Similarly, NDF and ADF increased significantly on crossing, which suggested that hybrids were more fibrous than parents and hence responsible for the negative and significant heterosis observed for digestibility. But it should be noted that, although hybrids appeared poorer in stover feed quality traits, increased fiber is desirable from a fitness perspective that makes the hybrid resistant/tolerant to environmental stress and diseases (Buxton and Casler, 1993). That means survival should not be compromised by improved stover quality. However, a threshold level at which both traits show optimum performance should be determined to avoid the penalty on either of the traits due to improvement in the other.

Combining ability

The sum of squares due to crosses was partitioned into lines, testers and line by testers (L×T) sum of squares using the line by tester procedure (Singh and Chaudhary, 1985; Dabholkar, 1999). Mean squares due to general combing ability (GCA) of both lines and tester, and specific combining ability (SCA) of line by tester interactions were significant (P≤0.01, P≤0.05) for all the traits studied except GCA of lines for grain yield and SCA of line by testers for ME and IVOMD (data not shown).

The proportional contribution of GCA (lines and testers added together) and SCA (L×T) was also calculated as the ratio between sum of squares of each component and the cross sum of squares (Singh and Chaudhary, 1985). The greater proportional contribution for most of stover feed quality traits were attributed to GCA (Fig. 1) indicating that additive gene effects were more important in the control of stover feed quality and

Table 4. Minimum and maximum values of mid and high parent heterosis for grain yield and various stover feed quality traits.

	Mid parent heterosis		High parent heterosis	
Traits	Minimum	Maximum	Minimum	Maximum
GY (t ha^{-1})	29.0*	202.3**	17.0	175.5**
SY (t ha^{-1})	6.3	106.7**	−5.4	93.1**
TBY (t ha^{-1})	24.9*	149.9**	12.4	130.7**
N (%)	−38.1**	-0.5	−41.6**	−3.2
NDF (%)	−1.6	4.7**	−2.8*	4.5**
ADF (%)	−1.0	11.9**	−1.3	9.7**
ME (%)	−8.5**	−0.0	−13.7**	0.7
IVOMD (%)	−8.7**	−0.3	−13.8**	−1.5

Source: Berhanu, 2009. GY = grain yield, SY = stover yield, TBY = total biomass yield, N = nitrogen, NDF = neutral detergent fiber, ADF = acid detergent fiber, ME = metabolizable energy, IVOMD = in vitro organic matter digestibility, * = statistically significant at P ≤ 0.05, ** = statistically significant at P ≤ 0.01.

quantity parameters. The only exception observed was ADF, in which case the contribution of GCA and SCA to the total variation among the crosses was almost similar. Because of the predominance of GCA, selection for most of the stover feed quality traits could be carried out at an early stage of inbred line development. Similar observation was made by Mosisa *et al*. (2008) for secondary traits under both high and low soil nitrogen conditions.

L2 (CML202), L3 (Gibe1-132-1-1-3), L10 (CML144) and T4 (PO'00E-4-2-2) contributed positively in a significant amount for grain and stover yields; thus, indicating the possibility of identifying inbred lines that could combine simultaneously to increase grain and stover yield (Fig. 2a). On the contrary, these inbred lines combined positively and non-significantly for some important stover feed quality traits and negatively for others, i.e., none of these inbred lines combined in a desirable direction for all of the stover feed quality traits (Berhanu, 2009).

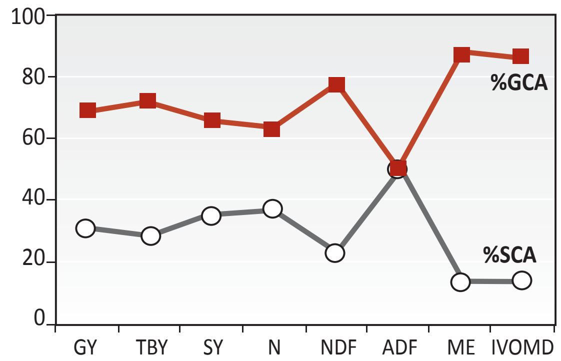


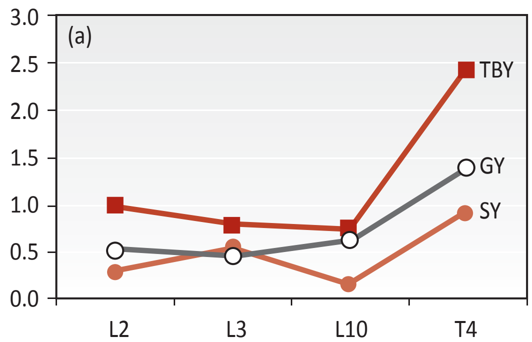
Figure 1. Proportional contribution of general combining ability (GCA) and specific combining ability (SCA) of grain yield and stover yield and quality traits. GY = grain yield, SY = stover yield, TBY = total biomass yield, N = nitrogen, NDF = neutral detergent fiber, ADF = acid detergent fiber, ME = metabolizable energy, IVOMD = in vitro organic matter digestibility.

On the other hand, L1 (NSCM41188 (32)), T1 (POOL9A-128-5-1) and T2 (DE-105-126-30-1-2-2) combined in a desirable direction for most important stover feed quality traits while combining neutrally for grain and stover yield parameters, i.e., combined positively and significantly for digestibility and metabolizable energy and negatively and significantly for fiber constituents (Fig. 2b). This group of inbred lines can be used for improving stover feed quality traits without significantly affecting grain and stover yield in hybrids (Berhanu, 2009).

Based on the SCA of crosses, some best cross combinations were observed that can be suitable for a food–feed purpose. Estimation of SCA effects for all of the traits studied showed that some combinations of inbred lines had effects that were significantly higher or lower than what had been predicted based on their parental performances. This deviation is usually attributed to genetic variation caused by non-additive gene effects such as dominance and different types of epistasis. Such promising crosses can be used for further breeding work and/or for direct release for use in the mixed maize-livestock farming system (Berhanu, 2009).

Phenotypic correlation

Grain yield showed a highly significant and positive relationship with stover yield (Table 5). The positive relationship observed between grain and stover yield clearly indicated the possibility of simultaneously increasing both traits. In eight maize varieties evaluated in Ethiopia, Adugna *et al.* (1999) also observed a positive association between grain yield and total biomass yield. Breeding programs targeting the improvement of either of the traits can achieve parallel increases in both traits. Genes governing the inheritance of these two traits might be tightly linked or both traits may be controlled by the same genes having pleiotropic effect (Hallauer and Miranda, 1988). Another interesting result is that neither of the yield parameters



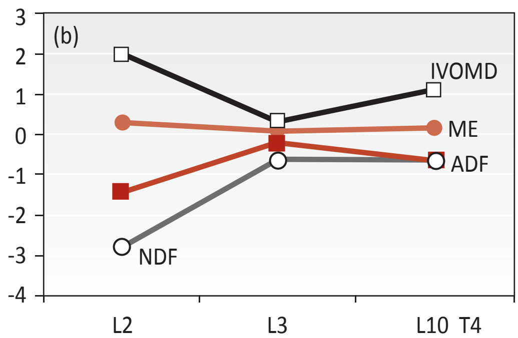


Figure 2. (a) General combing ability (GCA) of selected lines for grain yield (GY), stover yield (SY) and total biomass yield (TBY), (b) GCA of selected inbred lines for neutral detergent fiber (NDF), acid detergent fiber (ADF), metabolizable energy (ME) and *in vitro* organic matter digestibility (IVOMD).

(grain and stover) were significantly correlated with any of the stover feed quality parameters, except nitrogen, suggesting lack of any association between the yield parameters and stover feed quality traits. Based on this result, one may conclude that grain yield and stover yield can be improved without significantly affecting stover feed quality traits. In the same manner, stover feed quality traits can be improved without significantly affecting grain and stover yield parameters. According to the current finding, there is no need for formulating separate breeding programs to deal with the improvement of food and feed traits. The possibility of simultaneous improvement of these important traits in breeding programs will lead to maximal use of limited resources and avoidance of duplication of efforts. Nitrogen in stover showed significant negative association with grain and stover yields. The current finding is in agreement with previous studies which reported negative association between grain yield and crude protein content (Adugna *et al.,* 1999) and an inverse relationship between stover nitrogen and grain yield (Blummel *et al.,* 2007). However, stover nitrogen (crude protein) can be improved by increasing the amount of nitrogen in the soil to the level that is economically feasible (Blummel *et al.,* 2007; Mosisa *et al.,* 2007). Improvements in the cultural practice of maintaining cropping soil is important since nitrogen in stover has positive and significant association with metabolizable energy and stover digestibility. Any effort directed towards the increase of nitrogen content in stover consequently results in improved digestibility and metabolizable energy.

Stover feed quality traits also showed different levels of relationship among themselves. As expected, NDF showed a positive association with ADF while NDF showed a significantly negative relationship with metabolizable energy and digestibility. Metabolizable energy and digestible energy produced significantly positive relationships with each other. The correlation coefficient between these two traits was positive with a probability of less than 0.01. This indicated the existence of perfect association between these two parameters, implying the possibility of improving both traits simultaneously and reducing the cost of chemical analysis.

Conclusion and Future Direction

Various studies presented in this paper indicate significant genotypic variation for grain and stover yields and stover feed quality traits. The inbred lines from the mid-altitude and highland agro-ecologies showed variation for almost all the traits considered. The variation can be exploited in hybrid combinations and/or synthetics. The results of hybrid trials also clearly indicated the existence of genotypic variation across different environments. This gives a good confirmation that these traits are heritable, but demands selection of appropriate parental combinations at the right stage. In fact, most quality parameters showed negative heterosis, indicating poor performance of crosses as compared to their parents. However, crosses may possess acceptable levels of the traits under consideration. Therefore, it is good to establish a threshold level for each quality parameter so that a known acceptable level is checked every time quality is analyzed regardless of the heterosis value.

Another exciting result obtained in the different studies discussed in this paper, though data was not shown for some, is the existence of a positive association between stover yield and grain yield. One trait can be improved while improving the other. The relationship of both traits with stover feed quality traits was neutral and therefore the increase of either grain yield or stover yield had no effect on stover feed quality traits and vice versa. As a result, the same breeding program dealing with grain yield can equally handle the improvement of stover yield and stover feed quality traits provided that a quality detection facility is within the reach of breeders.

Table 5. Phenotypic correlation (r) between food and feed traits among 63 maize hybrids evaluated at Bako, Hawassa and Jimma in Ethiopia, 2008.

	GY	TBY	SY	N	NDF	ADF	ME	IVOMD
GY (t ha^{-1})	1	1.0**	0.8**	–0.3*	0.0	0.2	–0.1	–0.1
TBY (t ha^{-1})		1	0.9**	–0.3**	0.0	0.1	–0.1	–0.1
SY (t ha^{-1})			1	–0.3**	0.0	0.1	–0.1	–0.1
N (%)				1	–0.7**	–0.2	0.7**	0.7**
NDF (%)					1	0.4**	–0.5**	–0.6**
ADF (%)						1	–0.1	–0.1
ME (%)							1	1.0**
IVOMD (%)								1

GY= grain yield, TBY = total biomass yield, SY = stover yield, N = nitrogen, NDF = neutral detergent fiber, ADF = acid detergent fiber, ME = metabolizable energy, IVOMD = in vitro organic matter digestibility, * = statistically significant at P ≤ 0.05, ** = statistically significant at P ≤ 0.01.

The ever increasing human population is exacerbating the shortage of grazing land by converting free and communal grazing lands for crop production. To alleviate this problem, two strategies can be used. The first is cereal breeding programs in general and maize breeding in particular should give due emphasis to the incorporation of stover yield and feed quality as major traits during new variety development. The positive relationship observed for grain and stover yields and neutral relation between yield and stover feed quality parameters has given a glimmer of hope in this regard. However, simple and easy to use (breeder friendly) techniques and instruments should be available so as to enable the breeder to measure stover feed quality traits directly in the field. Given the availability of such materials and techniques, the breeder can have a good deal of knowledge and understanding about the genetic potential and variability among breeding germplasm. Accordingly, they can use different techniques of breeding, like introgression and hybridization, for further enhancement of this germplasm. As a second option, the breeding programs may enhance their capacity to further increase the productivity of dual-purpose food–feed maize varieties for intensive cultivation so that no additional grazing land is cultivated for food or feed grain production. However, these two options can be used simultaneously to address the problem more effectively and in a timely manner.

In Ethiopia, maize stover has diversified uses. While advocating the improvement of maize stover for yield and quality, it is important to clearly understand the competing uses of maize stover. Excessive removal of stover for animal feed, fuel and fencing particularly affects the fertility of the soil by hindering the return of organic matter back to the soil. This significantly affects the productivity and sustainability of the soil. Hence, research intervention is important to determine the amount of stover to be maintained in the soil for its sustainability. Another good option that can go along with the use of stover for feed is the introduction of agro-forestry practices in the farming system. In particular, the introduction of leguminous plants as a hedge will help farmers to minimize the amount of stover removed from the soil because farmers can obtain some amount of feed from the hedge rows and the leguminous plants have the ability of maintaining the fertility of his field.

Generally, the use of stover as animal feed is a widespread practice in the maize belt areas of Ethiopia. At this point we are not in a position to argue about the merits and the demerits of the practice. However, we believe that a systematic and science-based intervention is a must to maintain the cropping system. To this end, we have tried to indicate some of the options based on our studies which we believe are relevant institutional interventions to avert the shortage of feed for livestock.

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Dual-Purpose Crop Development, Fodder Trading and Processing Options for Improved Feed Value Chains

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Introduction

The inability of producers in developing countries to feed animals adequately throughout the year remains the major technical constraint in most livestock systems (Ayantunde *et al.,* 2005). Meeting the predicted future demand for meat and milk (Delgado *et al.*, 1999) in a way that poor livestock keepers benefit more from their animal assets will require sustainable inputs of labor, land, water and nutrients to produce the feed required. The increasing demand for livestock products offers market opportunities and income for small holder producers and even landless producers thereby providing pathways out of poverty (Kristjanson, 2009). However, lack of arable land and an increasing lack of water severely limit the options to produce the feed required to support the livestock revolution. As a result, crop residues (CR), which do not require specific allocation of either land or water, are already major feed resources, and their importance is likely to increase in the decades to come.

CR are generally considered to be of low nutritive quality, but this statement implicitly relates to cereal CR, since leguminous CR can have excellent fodder quality and are often valued as supplementary feeds. Until recently, the feed quantity and quality of especially cereal CR was largely ignored in crop improvement programs, although farmers are aware of differences in the fodder quality of CR even within the same species (Kelley *et al*., 1996) and make variety choices accordingly. In India this neglect sometimes resulted in new cultivars that had been only improved for grain yields being rejected by farmers because of low CR quantity and quality (Kelley *et al*., 1996). Against this background, research in the past decade considered the inclusion of feed related parameters in crop breeding and selection programs – often referred to as multidimensional crop improvement (Lenne *et al*., 2003; Blümmel *et al*., 2009).

As outlined by Sharma *et al*. (2010) increasing the feeding value of CR by multidimensional crop improvement depends upon: i) close collaboration between crop and livestock scientists, ii) nutritionally significant cultivar-dependent variation in CR fodder quality, iii) sufficient independence between CR fodder traits and primary traits such as grain and pod yield, and iv) technologies for quick and inexpensive phenotyping of large sets of samples for fodder quality traits. The utilization of improved CR can then be further enhanced through a value chain approach through fodder trading, supplementation and feed processing options. Here we discuss these dimensions in relation to crop residue use and development as feed resources based on research in India, Ethiopia and Kenya.

Importance of Crop Residues as a Feed Resource

Through coordinated central government and state efforts, India has systematically quantified fodder resources, building up a database from a district level (NIANP, 2003). Feed sources were classified into greens (subclasses: cultivated fodder, grass from grazing, grass from forests), crop residues (subclasses: coarse and fine cereal residues, leguminous residues) and concentrates (subclasses: grains, cakes, bran, chunnies; leguminous threshing residues). Subclasses from CR were further differentiated to list the contributions from specific crops (Table 1). In summary, the feed resource database

Table 1. Potential availability of different feed resources in India.

Feed resource	Availability (million t)
Greens	
From forest area	89.4
From fallow lands	23.2
From permanent pastures and grazing areas	28.7
From cultivable waste lands and miscellaneous tree crops	17.5
From cultivated fodder crops	303.3
Total from greens	462.1
Crop residues	
Coarse straw (from coarse cereal crops and sugarcane tops)	154.8
Fine straw (rice and wheat straw)	194.1
Leguminous straw (from pulses and other leguminous crops)	44.4
Total from crop residues	393.4
Concentrates	
Oil cakes	15.8
Brans	13.3
Grains for feeding livestock	5.7
Chunnies (threshing residues pulses)	0.53
Total from concentrates	35.3
Total from all feed resources	891

Source: NIANP (2003).

showed that crop residues were the most important single fodder resource in the nation. At the same time fodder from common property resources (CPR), forests, pastures and fallow lands constituted less than 18% of the available fodder and was declining. Also notable was that concentrates represented a very low proportion (< 4%) of the available feed resources, and there was no indication of any rapid increase in the use of concentrates. More recently Ramachandra *et al*. (2007) pointed out that CR will provide more than 70% of the feed resources for Indian livestock by the year 2020. While few systematic feed inventories exist yet in East Africa, there are clear indications that CR will become more important as feed resources through the conversion of common properties/pastures to crop land (Table 2). Within 30 years, crop land has doubled at the expense of common properties resources/pastures. Furthermore, in a 2010 survey of 24 villages in Ethiopia and Kenya, farmer groups were asked questions about trends in crop residue use in the last 10 years. When asked about whether crop residue use for feeding livestock had increased or decreased in the last 10 years, 100% of responses indicated an increase. When asked about use of crop residues as soil mulch, 86% of responses indicated a decrease (Kindu Mekonnen, 2011 unpublished data). In a further study of 90 villages across India and Ethiopia in 2010, farmers were asked about the contribution of various feed resources to the diets of their dairy cows. As seen in Fig. 1 comparisons within the country across low and high intensity systems indicates that grazing resources are declining in importance and use of crop residues is increasing as systems intensify. Furthermore, comparisons between India and Ethiopia also indicate generally more intensive systems in India, grazing resources have declined in importance to be replaced by crop residues and we can expect a similar trend in coming years in sub-Saharan African systems as they also intensify. Crop residues are thus clearly key feed resources which are becoming more important in East Africa as systems intensify and traditional common grazing resources come under pressure from growing human populations.

Table 2. Changes in land-use pattern around the Yerer area in Ethiopia 1972–2000.

Land cover type	Area (ha) 1971/72	Area (%) 1971/72	Area (ha) 2000	Area (%) 2000
Agriculture	7,186	25.0	16,204	56.4
Forestry	2,581	9.0	2,696	9.3
Water reservoirs	190	0.0	312	1.1
Wetlands	0	0.7	132	0.5
Pasture	18,784	65.3	9,397	32.7
Total	28,741	100.0	28,741	100.0

Source: Data from Kahsay Berhe 2004.

Fodder Markets for Stover

For multidimensional crop improvement that attempts to concomitantly improve grain and crop residue fodder traits, surveys of fodder markets trading crop residues reveal several important pieces of information, such as grain-crop residue price ratios, crop residue price-quality relationships, preferences for crop residues from certain species or cultivars, seasonal and spatial pattern in crop residue transactions and so on. Farmers, fodder traders and dairy producers are well aware of differences in stover fodder quality that are relevant for livestock nutrition within a species. Blümmel and Rao (2006) surveyed six major sorghum stover traders in Hyderabad monthly from 2004 to 2005 and observed that a total of six different stover types were frequently traded. At most times, customers had the choice between two and occasionally three different sorghum stover types offered by the same trader. The poorest and best quality stover (perceived in sensory terms of color, softness, sweetness etc measured against feedback from the customers, the dairy producers) were sold on average for 3 and 4 IRs kg^{-1} dry matter,

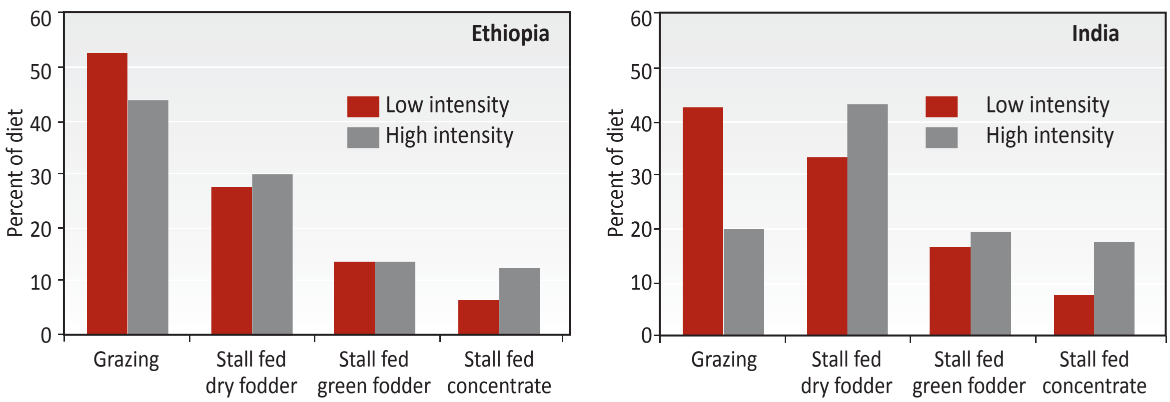

Figure 1. Effect of system intensity on farmers' estimates of the percent of dairy cow diets coming from different feed resources.

respectively. Blümmel and Rao (2006) investigated these traded stovers for laboratory fodder quality traits such as crude protein and *in vitro* digestibility and related these laboratory traits to stover prices (Fig. 2 and Fig. 3). While stover crude protein content was not related to stover prices, *in vitro* digestibility accounted for 75% of the variation therein. A difference of five percentage units in *in vitro* digestibility (47% versus 52%) was associated with a price premium for stover quality of 35% and higher (Fig. 2 and Fig. 3).

Interestingly, work by Gebremedhin *et al*. (2009) who investigated fodder markets in Ethiopia showed that price premium obtained for higher quality sorghum stover were comparable to those observed by Blümmel and Rao (2006) in India. Stover from sweet sorghums have about 3–4 percentage units higher *in vitro* digestibility than stover from "ordinary" grain sorghum (Blümmel *et al*. 2009). It can be calculated from the data of Gebremedhin *et al.* (2009) that sweet sorghum stover achieved about 30% higher prices than grain sorghum stover in fodder trading and about 54% higher prices at the farm gate (Table 3). Thus while intuitive differences in *in vitro* digestibility of 3–5 percentage units may appear "small", they do matter as the fodder market surveys have shown. In an *ex-ante* assessment, Kristjanson and Zerbini (1999) had calculated that a one percentage unit increase in digestibility in sorghum and pearl millet stover would result in increases in milk, meat and draft power outputs ranging from 6 to 8%. These findings agree also with breeding work by Vogel and Sleper (1994) who reported that 3 to 5% units in grass forage digestibility were associated with 17 to 24% differences in animal performance.

The considerable monetary value of straw and stover as livestock feed was also observed by Lukuyu *et al*. (2011) in Kenya. The income from high quality CR such as oat straw could approach that of oat grain (Table 4). Income from maize stover was 40% of the income from maize grain and income from barley straw was about 30% of grain.

Multidimensional Crop Improvement

These variations in stover fodder quality did not come about through pro-active plant breeding, and the awareness of variation in quality and the development of differential pricing probably took considerable time. As shown by the collaboration between the Indian National Research Center for Sorghum (NRCS) and ILRI, in which new sorghum cultivars submitted for testing to NRCS for release have been phenotyped for fodder quality since 2002 (Blümmel *et al.,* 2010), livestock nutritionally relevant variations in stover quality can be targeted and exploited in a wide range of *Kharif* and

Table 3. Price differences (in Ethiopian Birr, ETB) between stover from sweet sorghum and grain sorghum traded at Mieso, April 2007 (calculated from Gebremdhin *et al.,* 2009).

Stover	ETB kg^{-1} trader	ETB kg^{-1} farm gate
Sweet sorghum	0.7	0.2
'Grain' sorghum	0.5	0.1
Price premium	30%	54%

Table 4. Income (Kenyan Shilling) from selling grain and from selling straw and stover (crop residue, CR) as fodder in project sites of the East African Dairy Development Project in Kenya.

Crop	Grain	CR	Grain: CR	Price kg^{-1} CR
Oats	90,000	75,000	1.2	13
Barley	49,750	16,000	3.1	13
Maize	60,000	24,000	2.5	3

Source: Lukuyu *et al*. (2011).

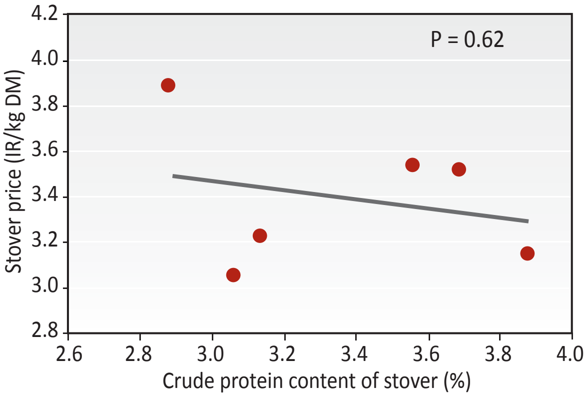

Figure 2. Relationship between sorghum stover protein content and prices in stover collected monthly in Hyderabad (2004–2005).

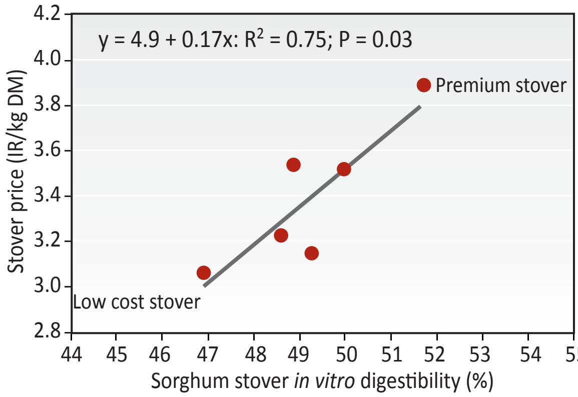

Figure 3. Relationship between sorghum stover digestibility and prices in stover collected monthly in Hyderabad (2004–2005).

Rabi sorghum with little or no trade-off between grain and stover traits (see Fig. 4 and Fig. 5). Sorghum stover digestibility in very high grain yielding *Kharif* cultivars varied over a range of almost 10 percentage units which is almost double the variation observed in samples collected in the studies of stover trading (see Fig. 3). An overall trade-off effect between stover quality and grain yield was observed for off-season (*Rabi*) sorghum, where stover digestibility accounted for 30% of the variation in grain yield (Fig. 4). However, stover digestibility among the highest grain yielding cultivars still varied across a range of more than five percentage units and cultivars where superior stover quality could be chosen without sacrificing grain yield. Similarly, stover digestibility was not negatively related to stover yield (Fig. 5) and stover yield itself was quite independent of grain yield (data not shown). There exists, therefore, a significant genetic variation for grain yield, stover yield and stover fodder quality and at the same time considerable independency between these traits.

More recently, work on dual purpose maize has been initiated in East Africa and South Asia national agricultural research systems (NARS) supported by the German Ministry of Technical Cooperation (BMZ) and the Bill and Melinda Gates Foundation (BMGF) through funding to ILRI and CIMMYT. Initial findings suggest that significant variations in maize stover fodder traits related to nutritional value for livestock exist (Fig. 6 and Fig. 7). While stover fodder quality traits and grain yields were inversely related when maize was deliberately grown under water restriction (Fig. 6), no such trade-offs were observed in conditions where water was not limited (Fig. 7). The findings in Fig. 7 are particularly interesting since they present an attempt to concomitantly improve grain yield and stover quality in maize by identifying and using elite inbred lines, development of single cross hybrids and finally production of F_1 hybrids (Zaidi *et al.,* unpublished). Hybrids were generated with very high grain yields and very high stover digestibility (Fig. 7).

Value Chains for Stover

While multidimensional crop improvement will contribute to increasing the quantity and quality of the basal diet, further feed technological interventions are required for achieving a significant impact on livestock productivity. A combination of feed ingredients through supplementation targeting synergistic – that is more than additive – feed interactions and physical intervention such as chopping, producing dense feed blocks etc seems promising (Shah, 2007). Miracle Fodder and Feeds PVT. LTD (Shah, 2007) designed so-called 'densified total mixed ration' (DTMR) feed blocks that consist largely of by-products such as sorghum stover (about 50%), bran, oilcakes, husks (about 36%) with the rest contributed by molasses (8%), maize grain, urea, minerals, vitamins etc. Miracle Fodder and Feeds PVT. LTD offers DTMR feed blocks of three different qualities, designed to produce daily milk yields of (in dairy buffaloes) 11–16 l (DTMR Diamond with 14.5–15% crude protein, 3.5% fat and 64–65% TDN), 7–11 l (DTMR Gold with 13.0 to 13.5% crude protein, 3.0% fat and 62% TDN) and 5–7 l (DTMR Silver with 11.5–12.0% crude protein, 2.5% fat and 60% TDN).

In a series of experiments, Miracle Fodder and Feeds Ltd Pvt ILRI explored the use of sorghum stover of different quality and the opportunity of substituting

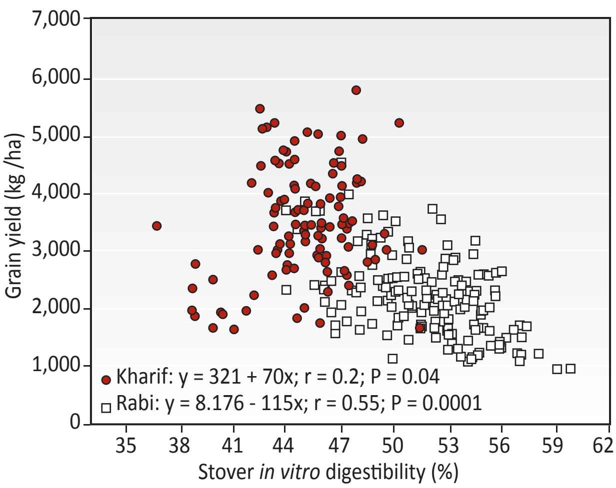

Figure 4. Relationship between mean stover *in vitro* digestibility and grain yield in *Kharif* and *Rabi* sorghum cultivars submitted to the Indian National Research Center for Sorghum (2002–2007).

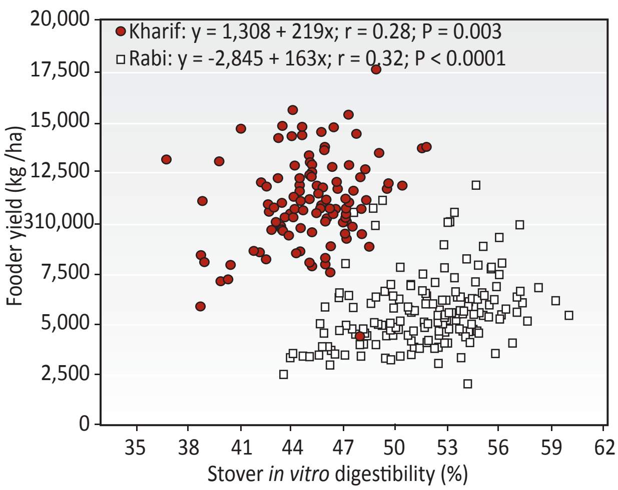

Figure 5. Relationship between mean stover *in vitro* digestibility and stover yield in *Kharif* and *Rabi* sorghum cultivars submitted to the Indian National Research Center for Sorghum (2002–2007).

sorghum stover with maize stover. In an experiment with a large private dairy (Anandan *et al.,* 2010), two experimental feed blocks based on DTMR Diamond were produced from lower (Telangana) and premium (Raichur) quality sorghum varieties (Fig. 3). Daily milk yield on Raichur based blocks was about 1 l more than in the group that received Telangana based feed blocks. At the start of this trial the buffalos were beyond peak lactation time (>100 days into lactation) and their metabolizable energy (ME) intakes relative to their ME requirements (ICAR, 1998) ended up being 151 and 130% in Raichur and Telangana groups, respectively. This ME intake above requirement (maintenance and actual level of milk production) would be sufficient for an additional milk yield of 8.7 and 4.8 l daily in the Raichur and Telangana groups, respectively. The daily advantage in milk yield from premium stover based blocks would therefore be close to 5 l. The overall potential production level would be 16.7 and 11.4 l of milk daily. These findings demonstrate that very respectable levels of productivity can be achieved on almost completely by-product based feeding systems. Furthermore, using a higher quality stover as a basal feed ingredient will pay off since the overall quality of the diet is higher (see ME values in Table 5) and the animals will eat more of this higher quality diet (see dry matter intake, DMI, in Table 5). Thus the decision of dairy producers to pay a 20 to 30% price premium for a stover quality difference of 3–5 percentage units in *in vitro* digestibility (Fig. 3 and Table 3) is economically rational.

In rain-fed Indian agriculture, strong farmer and dairy producer perceptions exist on the superiority of sorghum stover over maize stover which has effectively resulted in under utilization of maize stover (Erenstein *et al*., 2011). However, these negative perceptions are not really tenable. Table 6 shows the performance of beef cattle on the commercial sorghum stover-based feed block (CSSFB) of experiments conducted by Miracle Fodder and Feeds Ltd Pvt with an experimental feed block (EMFB) based on stover from maize hybrid HYTECH 5101, a hybrid with dual purpose traits. The blocks were fed *ad libitum* to growing bulls with a live weight (LW) of about 180 kg at the start of the experiment. Intake (DMI) and changes in live weight (LWC) were recorded. The findings show that sorghum stover can be substituted for maize stover without negatively influencing performance.

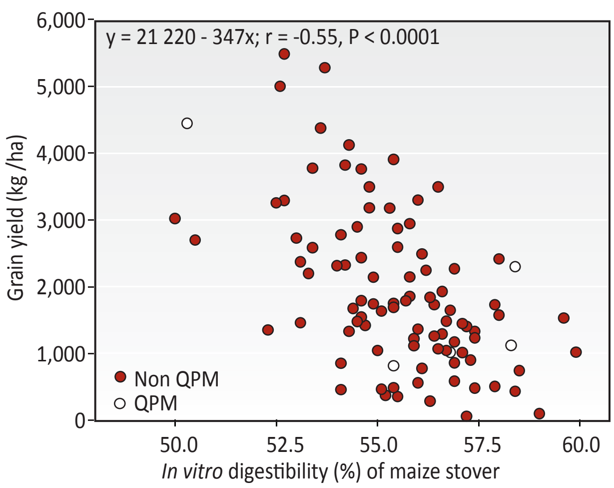

Figure 6. Relationship between maize stover digestibility and grain yields in 96 maize hybrids grown under water restriction.

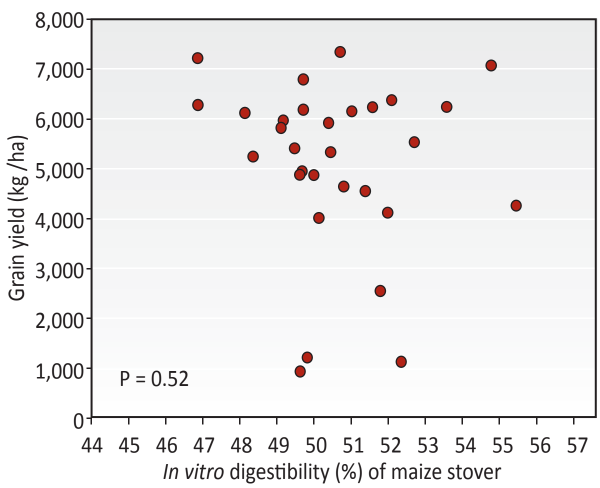

Figure 7. Relationship between maize stover digestibility and grain yields in 30 experimental maize hybrids designed for grain and stover traits.

Table 5. Response of dairy buffalo to complete total mixed ration feed block designed from sorghum stover of different qualities

	Block premium stover	Block low cost stover
Protein content	17.2 %	17.1 %
Metabolizable energy (ME)	8.5 MJ kg^{-1}	7.4 MJ kg^{-1}
Dry matter intake (DMI)	19.7 kg day^{-1}	18.0 kg day^{-1}
Milk potential	16.6 kg day^{-1}	11.8 kg day^{-1}

Table 6: Live weight gains of bulls fed sorghum and maize stover based feed blocks

	Commercial sorghum stover-based feed block	Experimental feed block
Protein content (%)	11.3	10.1
Metabolizable energy (MJ kg^{-1})	8.2	8.2
Live weight gain (g day^{-1})	820	850

Summary

Maize stover is a key feed resource in mixed crop livestock systems in both South Asia and East Africa. In East Africa, crop residue resources are becoming ever more important as grazing resources decline. Crop residues are generally considered to be poor quality feed resources which cannot support high productive livestock production. However, price quality relationships determined in India and Ethiopia show that farmers will pay a premium for quality. Furthermore, there exists considerable variation in stover quality of existing cultivars that could be exploited to support considerably higher levels of productivity than are currently being achieved if cultivars with higher stover quality were more readily available. Multi-dimensional crop improvement has considerable potential to enhance stover quality and thus help to support the increased productivity in smallholder systems that will be required to fulfill the increased demands for milk and meat predicted for coming years.

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Molecular Breeding and Biotechnology for Maize Improvement in the Developing World: Challenges and Opportunities

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Introduction

Maize holds a unique position in world agriculture as a food, feed for livestock and as a source of diverse, industrially important products. It accounts for 15–56% of the total daily calories of people in developing countries, and is currently produced on nearly 100 million hectares in 125 developing countries and is among the three most widely grown crops in 75 of those countries (FAOSTAT, 2010). For 900 million farmers and consumers in low- and middle-income countries, maize is the preferred crop or food. Between now and 2050, the demand for maize in the developing world will double and by 2025 it will have become the crop with the greatest production globally and in the developing world (Rosegrant *et al.,* 2008). The growth in demand for human consumption of maize in the developing world is predicted to be 1.3% per annum until 2020. Moreover, rising incomes are expected to result in a doubling of consumption of meat across the developing world (Naylor *et al.,* 2005), leading to a predicted growth in demand for feed maize of 2.9% per annum. However, maize harvests at current levels of productivity growth will still fall short of demand, unless vigorous measures are taken to accelerate the yield growth.

The average maize yields in several of the African countries, where maize is a highly important staple food crop, are still below 1 t ha^{-1}, while many countries have only 1–2 t ha^{-1}, due mainly to poor soil fertility, frequent occurrence of droughts, high incidence of insect-pests, diseases and weeds, farmers' limited access to fertilizer, and the lack of access to improved maize seed. Similarly, maize yields in many Asian countries remain low, with India, Nepal and the Philippines achieving ~2 t ha^{-1}, Indonesia and Vietnam ~3.5 t ha^{-1}, Thailand almost 4 t ha^{-1}, and China 5 t ha^{-1}, compared to the world average of 4.7 t ha^{-1} in 2005 and current USA average of 9.4 t ha^{-1} (Prasanna, *et al.,* 2010). Increasing maize yield by even 1 t ha^{-1} in the low-yielding maize environments of sub-Saharan Africa and Asia could deliver a much higher relative impact on food security and poverty alleviation than does the same increase in the high-yielding environments. The importance of improving maize production and productivity in the developing world could be gauged by the fact that one-third of all malnourished children are found in systems where maize is among the top three crops (Hyman *et al.,* 2008).

The challenges being imposed by the global climate changes are tremendous and real. The maize fields in many countries, especially in sub-Saharan Africa and South Asia, are now increasingly experiencing rising temperatures, more frequent droughts, excess rainfall/flooding, as well as new and evolving pathogens and insect pests. One of the key emerging challenges is to develop high-yielding cultivars with tolerance/resistance to combinations of adaptive traits, including drought + heat stress tolerance, and drought tolerance + disease resistance. The future of maize production, and consequently the livelihoods of several million smallholder farmers worldwide, is therefore based, to a great extent, on breeding. However, breeding alone will not provide sustainable solutions, and needs complementation with sustainable crop and natural resource management practices, as well as socio-economic interventions for maize futures (effective policies, institutions, technology targeting, and markets).

The technological opportunities for maize improvement have increased tremendously in recent years. Significant strides have been made particularly with regard to understanding the phenotypic and molecular diversity in maize germplasm, identification of genes/quantitative trait loci (QTLs) influencing diverse traits, especially tolerance to important biotic and abiotic stresses, implementing marker-assisted selection (MAS) for improving biotic resistance and nutritional quality. Yet, the application of molecular breeding tools to accelerate genetic gains in the maize breeding programs of the developing world has barely begun. The genome sequencing of B73 (Schnable *et al.,* 2009) and Palomero, an important popcorn landrace in Mexico (Vielle-Calzada *et al.,* 2010) are important landmarks in maize research, with significant implications to our understanding of the maize genome organization and evolution, as well as strategies to utilize the rapidly expanding genomic information for maize improvement. As Virginia Walbot (2009) stated: "The overarching question now is how we can use the unprecedented genetic tool that the maize genome offers to improve corn productivity per unit of land while reducing inputs such as water and fertilizer so that we can sustain humanity's food requirements, while also decreasing the negative impacts of agriculture on the Earth."

Next-Generation Sequencers, High Throughput Genotyping and Genomic Resources

Advances in genomics led to the identification of numerous DNA markers in maize during the last few decades, including thousands of mapped microsatellite or simple sequence repeat (SSR) markers, and more recently, single nucleotide polymorphism (SNP) markers. In addition to the SSRs and SNPs, a large number of genes controlling various aspects of plant development, biotic and abiotic stress resistance, quality characters, etc. have been cloned and characterized in maize, which are excellent assets for molecular marker-assisted breeding.

Until recently, SSRs have been the most widely used markers by maize researchers due to their availability in large numbers in the public domain (Maize GDB, 2011; http://www.maizegdb.org), simplicity and effectiveness. There are now excellent opportunities for undertaking high throughput genotyping in maize using the SNP markers, as SNPs are highly amenable to automation, and offer significant advantages for genetic analysis and breeding purposes. Compared with the genomes of other cultivated plant species, SNP frequency in maize is high, with one SNP being found every 28–124 bp (e.g., Vroh Bi *et al.,* 2006). A database and resource for SNP discovery and trait dissection has been established for maize in which genotype, phenotype and polymorphism data can be accessed for diverse maize inbred lines and populations (http://www.panzea.org). Nearly one million maize SNPs are available in public databases (http://www.panzea.org), and several high throughput genotyping platforms have been developed for commercial use.

The new genotyping/sequencing technologies, and associated data handling and analysis tools, provide opportunities for the maize community to speed up research progress for large scale diversity analysis, high density linkage map construction, high resolution QTL mapping, linkage disequilibrium (LD) analysis and genome-wide association studies. Because the genomic sequence of maize is publically available (http://www.maizesequence.org/index.html), re-sequencing of individual maize inbred lines can now give the entire genotype of that individual, that is to say, the allelic state of every SNP in the genome. Expected advances in this technology should soon make it widely accessible, with SNPs available in every region of the genome, and advancing enormously the possibilities for gene discovery and selection.

In addition to powerful marker systems, diverse mapping populations are available in maize as international maize genomic resources. For example, the maize “nested association mapping” (NAM) population, comprising 5,000 recombinant inbred lines (RILs) (200 RILs from each of 25 populations), is an important genetic resource developed in recent years. The NAM population is a novel approach for mapping genes underlying complex traits, in which the statistical power of QTL mapping is combined with the high (potentially gene-level) chromosomal resolution of association mapping (Yu *et al.,* 2008). Global diversity has been captured in the NAM RIL germplasm resource, which will provide the maize research community with the opportunity to map genes involved for an array of traits of agronomic or scientific interest.

Understanding and Utilizing the Vast Phenotypic and Molecular Diversity in Maize

Although maize hybrids represent the most economically important portion of the species, breeding populations, open-pollinated varieties (OPVs) and landraces, contain the majority of the allelic diversity, much of which has never been incorporated into improved maize cultivars. A well-characterized and well-evaluated germplasm collection would have greater chances of contributing to the development of new varieties and, consequently, greater realization of benefits for resource-poor farmers. The CIMMYT Gene Bank holds ~27,000 maize entries, of which ~24,000 are landraces/OPVs collected from diverse regions in Latin America, Africa and Asia, held in trust for several decades (Ortiz *et al.,* 2010).

Maize landraces of the Americas and Europe, and more recently of Asia, have been subjected to intensive molecular analyses, leading to significant insights regarding their diversity and population genetic structure (e.g., Prasanna, 2010; Prasanna *et al.,* 2010; Sharma *et al.,* 2010; Warburton *et al.,* 2011). Comprehensive analysis of phenotypic and molecular diversity of these landraces and focused utilization in breeding programs assume great significance.

Studies using molecular markers have provided new insights into geographic distribution of genetic variation of maize landraces worldwide and their wild relatives (especially teosintes) in Latin America, understanding the patterns of genetic diversity in the maize gene pool, tracking the migration routes of maize from the centers of origin, and the fate of genetic diversity during domestication and adoption of advanced breeding procedures, etc. Molecular characterization of 770 maize inbred lines with 1,034 SNP markers has been recently undertaken at CIMMYT, leading to identification of 449 high-quality markers with no germplasm-specific biasing effects (Lu *et al.,* 2009). Genotyping-by-sequencing (GBS), coupled with rapid advances in bioinformatics, shall further revolutionize the rapid linking of genetic diversity and genomics in crops like maize.

Simultaneous with the wider adoption of high throughput molecular tools, there is a distinct need to establish a global phenotyping network for comprehensive and efficient characterization of genetic resources and breeding materials for an array of target traits, particularly for biotic and abiotic stress tolerance and nutritional quality. This would significantly accelerate genomics-assisted breeding, diversification of the genetic base of elite breeding materials, creation of novel varieties and countering the effects of global climate changes. A new initiative of CIMMYT, titled the 'Seeds of Discovery' (SeeD), aims to discover the extent of allelic variation in the genetic resources of maize and wheat, formulate core sets based on genotyping and phenotyping, and utilize marker-assisted breeding to bring those rare useful alleles into breeding programs for developing novel genotypes.

Genetic Dissection of Important Traits Using Molecular Markers

Maize researchers worldwide have generated numerous reports of molecular markers tagging genes/QTLs for diverse traits of agronomic and scientific interest. QTLs for several important traits affecting maize have been mapped, including resistance to several diseases (e.g., downy mildews, Northern corn leaf blight/*turcicum* leaf blight, common smut, *Fusarium moniliforme* ear rot, Banded leaf and sheath blight (BLSB), aflatoxins, etc.), abiotic stresses (e.g., drought, waterlogging, low nitrogen stress, etc.) and specialty traits (e.g., high-oil content, etc.). Such studies have contributed to a greater understanding of the genetic architecture of various traits, particularly disease resistance (e.g., Wisser *et al.,* 2006) and drought tolerance in maize.

Association mapping through linkage disequilibrium (LD) analysis has led to identification of many genes controlling several simply inherited traits in various plant species (Zhu *et al.,* 2008). This approach is now being applied to dissect complex traits and identify superior alleles contributing to improved phenotypes. Association mapping seeks to identify a statistically significant genetic association between a change in the DNA sequence and a change in a trait of interest using a large population of diverse individuals, to remove circumstantial correlations. The approach provides excellent mapping resolution and the ability to investigate many alleles at the same time. Although conventional linkage/QTL mapping and association mapping should be considered complimentary techniques to find and corroborate results, researchers will find that establishing an association mapping panel of fixed lines can be carried out more quickly than the generation of a fixed population of recombinant lines for linkage mapping, and the same association mapping panel may be used for the study of many different traits.

There are many reports of successful associations between DNA polymorphisms and qualitative traits in plants, but fewer reports for complex traits. However, the genetic, genomic, and statistical tools are now at hand to successfully apply association mapping for the dissection of complex traits in plants, using genome-wide association studies (GWAS) which will harness the natural diversity in the crop-related gene pool to identify and use allelic variants for crop improvement (Yu *et al.,* 2006; Zhu *et al.,* 2008). A maize association mapping panel including 527 inbred lines with tropical, subtropical and temperate backgrounds, representing the global maize diversity, was genotyped by CIMMYT researchers using 1,536 SNPs (Yang *et al.,* 2010); the study revealed that this maize panel is suitable for association mapping in order to understand the relationship between genotypic and phenotypic variations for complex quantitative traits using optimal statistical methods.

Powerful analytical techniques are also now available to scan the genome for significant marker-trait associations, to estimate epistatic effects among QTLs, and to study QTL × environment interactions. The importance of epistasis and QTL × environment effects on trait expression has been demonstrated for drought tolerance (Prasanna *et al.,* 2009) and other traits in maize. Also, meta-analyses to integrate results from QTL experiments undertaken in various environments/locations assumes importance in understanding the genetic basis of complex traits and devising suitable strategies to utilize the information in breeding programs.

Molecular Marker-Assisted Breeding for Maize Improvement

Significant progress has been made worldwide in optimizing MAS for improvement of both qualitatively and quantitatively inherited traits using maize as a model system. One important fact that emerges is that there is no single "recipe" for application of MAS in improving diverse and important traits in maize. The genetic architecture of the trait should decide the way in which the MAS-based interventions are to be made in breeding programs.

MAS for simply inherited traits

Simply inherited traits are those that are largely controlled by a few major genes, with high heritability (e.g., some of the nutritional quality traits like quality protein maize (QPM) and pro-vitamin A enrichment). One of the successful examples of MAS for maize improvement, and of particular use to the developing world, is the utilization of *opaque2*-specific SSR markers in conversion of maize lines into quality QPM lines with enhanced nutritional quality (Prasanna *et al.,* 2001; Babu *et al.,* 2005; Gupta *et al.,* 2009). A MAS-derived QPM hybrid, Vivek QPM Hybrid 9, has been recently released by the Vivekananda *Parvatiya Krishi Anusadhan Sansthan* (Vivekananda Research Institute for Hill Area Agriculture; VPKAS) at Almora, India. This QPM hybrid was developed through marker-assisted transfer of the *o2* gene and phenotypic selection for endosperm modifiers in the parental lines (CML145 and CML212) of Vivek Hybrid 9 (Babu *et al.,* 2005; Gupta *et al.,* 2009). This strategy was used to develop QPM versions of several elite, early maturing inbred lines adapted to the hill regions of India (Gupta *et al.,* 2009), as well as QPM versions of six elite inbred lines, which are the parents of three single-cross hybrids, at the Indian Agricultural Research Institute at New Delhi (Prasanna *et al.,* 2010).

Another potential application of MAS in maize could be for improving the pro-vitamin A content of grain. Quantifying the pro-vitamin A carotenoid content of maize samples is difficult, time-consuming and expensive, and breeding programs will therefore benefit greatly from use of MAS to reduce the need for phenotypic assays. Following the publication of results of association mapping studies (Harjes *et al.,* 2008), sequence-tagged, PCR-based markers were developed and demonstrated for use in selecting favorable alleles of *LCYE* (Lycopene epsilon cyclase), a crucial gene in the carotenoid pathway. More recently, collaborative research work by HarvestPlus led to the detection of important allelic variation and development of useful markers for favorable alleles of *LCYE* and another critical gene in the pathway, *CrtRB1* (Carotene beta-hydroxylase 1) (Yan *et al.,* 2010). Recent work undertaken through HarvestPlus, including phenotypic selection for deep orange ears, coupled with MAS for favorable alleles in the two critical genes (*LCYE* and *CrtRB1*) using seed DNA-based genotyping, indicates the strong potential of this strategy in improving the pro-vitamin A content in maize (CIMMYT-Harvest Plus, unpublished data).

MAS for polygenic traits

Several disease resistance traits in maize follow polygenic inheritance, governed by a few to many genes/QTL in each case, with low G×E, and reasonably high heritability. For such traits, the best possible strategy could be detection and validation of marker-trait associations, fine mapping for identifying breeder-friendly molecular markers (preferably SNPs), and pyramiding of the favorable alleles using such markers in the desired genetic backgrounds. CIMMYT is presently following this strategy for some of the important maize diseases, especially Maize Streak Virus (MSV), Gray Leaf Spot (GLS), and *turcicum* leaf blight, as these diseases have significant impact on maize production and food security in several developing countries.

Rapid-cycling genomic selection-based breeding for improving complex traits

Complex traits are those which are governed by many genes/QTL, with high G×E and low heritability (e.g., drought stress tolerance). The genome-wide selection or genomic selection (GS) is a potential strategy for enhancing genetic gains in breeding for such complex traits. This approach could help to effectively avoid issues pertaining to the number of QTL controlling a trait, the distribution of effects of QTL alleles, and epistatic effects due to genetic background (Bernardo and Yu, 2007). Genomic selection also relies on MAS and is under evaluation for the feasibility of incorporating desirable alleles at many loci that have small genetic effect when used individually. In this approach, breeding values can be predicted for individual lines in a test population based on phenotyping and whole-genome marker screens. These values can then be applied to progeny in a breeding population based on marker data only, without the need for phenotypic evaluation. Modeling studies indicate that this method can lead to considerable increases in the rates of genetic gain by accelerating the breeding cycles (Heffner *et al.,* 2009).

New breeding and selection strategies like GS rely on the availability of cheap, robust and reliable marker systems. Pilot projects on the implementation of rapid-cycling GS using much higher marker densities are being initiated by CIMMYT on new platforms based on next generation sequencing technologies, with the ultimate aim of its routine application across the CIMMYT and national agricultural research stations (NARS) maize breeding programs in sub-Saharan Africa, Latin America and Asia.

Critical Support Systems for Molecular Breeding

Precision and high throughput phenotyping

Our need for precision and high-throughput phenotyping is certainly not new. Long before the genomic era, improved techniques for assessing plant phenotypes were constantly explored in germplasm screening and cultivar development for various traits. Today, however, it is well-recognized by many institutions in both public and private sectors that high-throughput genotyping is no longer a major limiting factor, but precision and high-throughput phenotyping is. Although the scientific community currently relies heavily on phenotypic evaluations and/or wet chemistry for important traits, imaging techniques that allow immediate and non-invasive detection of plant characteristics, before visual appearance of phenotypes, are gaining prominence as they aid in high-throughput profiling of phenotypic characteristics.

High-throughput phenotyping protocols are now being developed and applied not only for shoot traits but also for root traits, which are particularly important in breeding for abiotic stress tolerance and improved water and nutrient use efficiency (e.g., Trachsel *et al.,* 2010). Similarly, NIRS (Near-infrared reflectance spectroscopy) can be used as a rapid, cost-effective, and accurate method for assessing differences in quality traits but also in providing data on breeding for genotypic differences in grain yield and stress adaptation (e.g., Montes *et al.,* 2007). Near-infrared reflectance spectroscopy protocols are being optimized for predicting ash and N contents and as a method for screening $\delta^{18}O$ in maize with promising applications in crop management and maize breeding programs for improved water and nitrogen use efficiency and grain quality (Cabrera-Bosquet *et al.,* 2010). Coupled with such developments are the advances being made in characterizing field variability as well as field-based phenotyping, including non-destructive estimation of biomass using NDVI (Normalized Differential Vegetation Index), monitoring soil moisture using neutron probes/time domain reflectometry (TDR), chlorophyll content using a SPAD meter, canopy behavior using Infrared thermography, etc.

Doubled haploid technology

Cost- and time-effective development of homozygous lines is an important component of maize breeding. Traditionally, homozygous lines are obtained by repeated selfings of heterozygous material for 6–7 generations, which is a time-consuming and expensive process. The induction and subsequent doubling of maternal haploids is an efficient alternative to generate homozygous lines in a quick timeframe (two generations). CIMMYT has adapted the doubled-haploid (DH) technology, in collaboration with the University of Hohenheim (Germany), to accelerate the development of homozygous lines in diverse, elite, highly adapted genetic backgrounds.

The DH technology is a powerful means to accelerate the introgression of novel germplasm into elite maize breeding lines. It enhances "forward breeding" and provides an opportunity to have an earlier look at the potential of new lines, greater knowledge about their environmental adaptability before they are fully tested, and further used as parental lines for hybrid development and commercial cultivation. Use of DH technology can potentially enhance the efficiency of recurrent selection or genomic selection based schemes for traits with low heritability, particularly for breeding programs without access to offseason nurseries (Bouchez and Gallais, 2000). Furthermore, the DH technology enables shifting of resources from the labor-intensive task of repeated inbreeding to generate inbred lines, and spending more time on evaluation of the DH lines for yield and other adaptive traits, and using the identified lines for producing hybrids and synthetics.

CIMMYT's research on DH technology, at present, is focused towards development of tropicalized haploid inducer lines (in both yellow and white kernel backgrounds) to meet the needs of the CIMMYT and NARS breeding programs in Africa, Latin America and Asia, in addition to optimizing agronomic management protocols for efficient, reliable and high-throughput DH line development.

Biometrics, breeding informatics and decision support tools

We cannot effectively take advantage of the genomic revolution without strengthening the capacity in breeding informatics and biometrics. The leading multinational maize seed companies have successfully exploited marker-QTL associations in population improvement and cultivar development (e.g. Johnson, 2004; Eathington *et al.,* 2007). Some of the important factors that contributed to effective use of MAS schemes in maize breeding, specifically by the private sector, have been the use of year-round nurseries or continuous nurseries, high-throughput genotyping and phenotyping, and efficient integration of phenotypic and genotypic datasets using bioinformatic tools for decision making (e.g., Ragot and Lee, 2007; Eathington *et al.,* 2007).

Information Management Systems, coupled with Decision Support Tools, need to be adopted by the public sector institutions in the developing world, as these can effectively help in linking the maps, markers and alleles on one hand with the germplasm, pedigree and phenotypes on the other.

Transgenic Technology and Public-Private Partnerships

Among the transgenic or genetically modified (GM) crops that are being grown worldwide, maize has an important place along with soybean, cotton and canola. GM crops occupied an area of 148 million hectares in 2010. Of the 29 Biotech/GM crop-growing countries, 16 have GM maize (James, 2011). Several transgenic maize products have been developed and released in the USA, mostly by the multinational concerns. Also, an array of transgenic maize products are in pipeline for release in many developing countries, including the Bt maize, herbicide resistant maize, maize with resistance to Maize Streak Virus (MSV), and those with stacked traits, mainly herbicide resistance + insect-resistance (Bt). One of the most significant advances in 2010 was that Mexico, the center of biodiversity for maize, successfully conducted the first field trials of Bt and herbicide tolerant maize (James, 2011).

GM crops are not a "magic bullet" in providing solutions to all the problems of agriculture, but the developing world should have access to all cutting-edge technologies, including GM, to improve agricultural production. CIMMYT recognizes the significance and judicious utilization of the GM technology in breeding improved maize genotypes for tackling some intractable problems, especially biotic and abiotic stress tolerance. Toward this, CIMMYT has established public–private partnerships with Monsanto under the Water Efficient Maize for Africa (WEMA) project through the African Agricultural Technology Foundation (AATF), and with Pioneer to work on nitrogen use efficiency under the Improved Maize for African Soils (IMAS) project.

Public–private partnerships are also important for strengthening maize molecular breeding in the developing world. Considering the high cost of molecular research platforms, the need for extensive and precise phenotyping, the increasing complexity of bioinformatics tools to manage and interpret data, and the ever-growing intellectual property rights restrictions to germplasm exchange, such partnerships offer a synergistic way for accessing cutting-edge technologies for maize improvement as well as effective sharing of scientific and infrastructure capacities.

Conclusions

The technological opportunities for maize improvement have increased tremendously in recent years. Significant strides have been made in applying molecular tools for genetic analysis of maize, particularly with regard to understanding the phenotypic and molecular diversity in maize germplasm, and identification of QTLs influencing diverse traits, especially tolerance to important biotic and abiotic stresses. Yet, the application of molecular breeding tools to accelerate gains in maize productivity has barely begun, and there is vast potential and need to expand the scope and impact of such operations. Breeders will want to avail molecular tools to more efficiently add value to new maize cultivars, e.g., by enhancing their nutritional or biochemical qualities for use as food, feed for livestock, and industrial material.

A major investment in the critical support systems required for molecular breeding, including breeding tools, DH technology, year-round nurseries, high-throughput and precision phenotyping facilities, automated DNA extraction, breeding informatics and biometrics, and dedicated personnel, is required for the developing countries to effectively deploy MAS, maximize selection gains, and minimize time required for cultivar development.

Failure to innovate, including introduction of the right GM traits for solving some intractable problems through partnerships, might result in diminished growth rates of crop productivity. Therefore, innovative models for resource-pooling, intellectual-property-respecting partnerships are required to gain access to cutting-edge technologies, including GM maize traits. Capacity strengthening in effective use of genotyping and phenotypic data, and application of genetic analysis and bioinformatics tools for maize improvement is key for sustainable application of the modern technologies in maize breeding strategies.

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Conservation Agriculture for Sustainable Maize Production in Ethiopia

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Introduction

Soil tillage is probably as old as settled agriculture. It has been therefore an integral part of traditional and/or conventional agriculture. Specific reasons for tilling a soil include weed control, incorporation of soil amendments, crop residues and pesticides, and modification of soil physical properties, thereby improving soil conditions for crop establishment, growth and yield (Cassel, 1983). The impacts of tillage on soil degradation and hence agricultural sustainability are more important now than ever before.

The concept of minimum tillage (MT), a combination of ancient and modern agricultural practices, was first introduced in the early 1950s when tillage was substituted by herbicides in pasture renovation. In the same decade, a similar concept was proposed for maize following sod with the emphasis on mulching to ensure soil and water conservation. Then, maize was planted with minimum tillage by removing plugs of soil with a sampling tube, dropping in a seed, and replacing the soil removed by the sampler, and much to the surprise the maize grew well (Moody *et al.,* 1961). Consequently, minimum tillage systems for crop production were rapidly adopted by millions of farmers in the world.

Minimum tillage usually coincides with the retention of crop residues on the soil surface. The residues of grain crops, especially, are often regarded as a lower quality crop residue resource. However, in Ethiopia it is one of the most abundant crop residue resources, and it can play a major role to improve the sustainability of cropping.

Tillage plays an important role in the dynamic processes governing soil degradation. Properly used, tillage can be an important restorative tool that can alleviate soil related constraints in achieving potential crop productivity and sustainability. Improperly used, tillage can set in motion a wide range of degrading processes like depletion of soil organic matter, decline in soil fertility, deterioration in soil structure and accelerated erosion.

No soil phenomenon is more destructive worldwide than soil erosion (Brady, 1990). It involves losing not only water and plant nutrients but ultimately the soil itself. Although soil erosion is widespread in all areas of sub-Saharan Africa, it is the most serious in Ethiopia, where topsoil losses of up to 290 metric tons ha^{-1} $year^{-1}$ have been reported for steep slopes (Mrema, 1996). It is estimated that Ethiopia loses about 1.5 billion tons of soil per year from agricultural lands (Hurni, 1989).

The major maize producing regions of Ethiopia have a high yield potential as a result of favorable environmental conditions; nonetheless, the soils are intensively cultivated, deforested and overgrazed. Maize is mainly cultivated by small-scale farmers depending on oxen power for tillage under rain-fed conditions. The conventional tillage (CT) system for maize production involves multiple passes 3–4 times plowing with oxen-plow until a fine seedbed is obtained over 3–4 months prior to planting. This bare and highly pulverized soil condition coincides with high, often intense rainfall which predisposes topsoil and water to losses, and results in highly degraded soils with very low soil fertility and productivity. Therefore, the problem of soil and water losses through surface runoff is one of the major limiting factors in agricultural production today in Ethiopia.

Conventional tillage is being displaced by minimum tillage (Phillips *et al.*, 1980). Minimum tillage coupled with crop residue management is widely recognized for its role in conservation of both soil and water (Lal, 1989) and eventually enhances crop yields (Moschler *et al.*, 1972; Phillips *et al.*, 1980; Tolessa *et al.,* 2007a). The crop residues remaining on the soil surface with minimum tillage provide not only essential physical protection to the soil particularly against erosion, but also make available decomposable biomass to the organic matter pool of soil which will improve fertility. Hence, minimum tillage with crop residue retention offers great hope for checking soil erosion, conserving moisture, and reducing the back-breaking drudgery of land preparation and hand weeding. The objectives of this study were therefore to evaluate the effects of tillage system and residue management on maize grain yield and some soil properties in Ethiopia.

Materials and Methods

The experiments were conducted on Nitisols in Bako and Jimma areas, western Ethiopia. The experimental plots were kept permanent to observe the carry-over effects of the treatments over years. For the minimum tillage treatments soil disturbance was restricted to the absolute minimum, *viz*., the soil was disturbed only to place the seed in the soil at the time of sowing. In contrast, for conventional tillage treatments the soil was plowed three times prior to sowing to obtain a suitable seedbed. Weed control in the minimum tillage plots was done by applying the herbicides glyphosate (Round-up©) at the rate of 3 l ha^{-1} prior to planting and lasso-atrazine at the rate of 5 l ha^{-1} as a pre-emergence application. The recommended weed control practice, *viz*,. twice hand weeding at 30 and 55 days after sowing followed by slashing at milk stage was adopted for conventional tillage maize.

The N uptake by grain (GNU) and stover (SNU) were calculated using the relevant yields and N contents and hence that of total biomass by summation of GNU and SNU. Then the N agronomic efficiency (NAE), N recovery efficiency (NRE) and N physiological efficiency (NPE) were calculated using equations 1, 2 and 3, respectively as noted by Bock (1984):

$$NAE = \frac{Y_i - Y_{i-1}}{N_i \text{ and } N_{i-1}} \qquad 1$$

$$NRE = \frac{NR_i - NR_{i-1}}{N_i \text{ and } N_{i-1}} * 100 \qquad 2$$

$$NPE = \frac{Y_i - Y_{i-1}}{NR_i \text{ and } NR_{i-1}} \qquad 3$$

Where, Y_i and Y_{i-1} represent grain dry matter yield and NR_i and NR_{i-1} N uptake by total biomass at N_i and N_{i-1} levels of fertilizer N application.

Labeled N used on a 2.4 m^2 micro plot was demarcated in the center of every selected 24 m^2 macro plot. Labeled ^{15}N at 5 atom % urea fertilizer was applied to the micro plots instead of unlabeled urea fertilizer which was applied as usual to the remaining part of the macro plots. The procedure, rate and time of N application were exactly the same as in the previous four years irrespective of the type of fertilizer used for this investigation.

At physiological maturity 0.4 m^2 of a micro plot was harvested for the determination of grain and stover yields. Representative grain and stover samples from the harvest area of every plot at all sites were collected to determine their N contents. The stover was chopped into smaller pieces before the grain and stover were dried, powdered and stored for analysis.

After harvesting, a metal frame having the same dimensions as the harvest area of a micro plot was pushed into the soil to facilitate the removal of soil layers from the actual harvest area. Soil layers were removed at 15 cm intervals down to a depth of 90 cm. A core sample was collected for bulk density determination (Blake and Hartge, 1986) before the soil from each layer was spread on a plastic sheet and thoroughly mixed before sub-samples were randomly collected to prepare a representative sample for every soil layer from a micro plot. These sub-samples were thoroughly mixed, dried at room temperature, sieved through a 2 mm screen and stored for analysis.

A standard steam distillation procedure was used for the determination of total N in the grain, stover and soil samples after they were digested in sulfuric acid (Hesse, 1971). The grain, stover and soil samples were also digested in sulfuric acid thereafter ^{15}N abundance was determined by mass spectrometry (Hauck, 1982).

The data from the micro plots were used in the calculations described below. Firstly, the percentage of labeled N recovery in the maize grain and stover (% ^{15}N*rm*) was calculated using Equation 4 as described by Weinhold *et al.* (1995):

$$\%\,^{15}Nrm = \frac{\text{atom \% excess in sample}}{\text{atom \% excess in fertilizer}} * 100 \qquad 4$$

Then the amount of grain and stover N derived from fertilizer (Ndff, kg ha^{-1}) and N derived from soil (Ndfs, kg ha^{-1}) were calculated using Equations 5 and 6:

$$Ndff = N\,uptake * \frac{\%\,^{15}Nrm}{100} \qquad 5$$

$$Ndfs = N\,uptake - Ndff \qquad 6$$

Lastly, N recovery efficiency (NRE, %) by the grain and stover were calculated using Equation 7 which is similar to that of Rao *et al.* (1992):

$$NRE = \%\,^{15}Nrm * \frac{N\,uptake}{N\,applied} \qquad 7$$

The percentage of labeled N recovery in the soil (% ^{15}Nrs) was calculated using Equation 8:

$$\%\,^{15}Nrs = \frac{\text{atom \% excess in sample}}{\text{atom \% excess in fertilizer}} * A * 100 \qquad 8$$

$$\text{where } A = \frac{\text{total soil N (g N g}^{-1}\text{ soil) *bulk density (g cm}^{-3})}{\text{\% N in fertilizer *g fertilizer applied cm}^{-2}} * \text{soil depth (cm)}$$

Then the amount of N fertilizer that remained in the soil (Nfrs, kg ha^{-1}) was calculated using Equation 9:

$$Nfrs = N\,applied * \frac{\%\,^{15}Nrs}{100} \qquad 9$$

The unit for N uptake and applied was kg ha^{-1}.

Results and Discussion

Effects of tillage system on maize grain yield

In most years the tillage systems and concomitant crop residue management significantly affected maize grain yield both at Bako and Jimma (Fig. 1 and Table 2). However, grain yield response to tillage varied substantially across years and this could be ascribed to the prevailing weather conditions, particularly the rainfall in specific growing seasons (Table 1).

In 2000 and 2001 the rainfall at Bako adequately soaked the soil during May and promoted early planting, thereafter the rainfall extended to September and resulted in favorable conditions for grain filling. In contrast to the 2000 and 2001 growing seasons, little rainfall occurred in May of 2002, 2003 and 2004 which caused late sowing of maize. This late sowing predisposed the maize crop to adverse environmental conditions such as early onset of water stress and desiccating winds in September and October during the anthesis and grain filling stages. These factors caused premature termination of growth which was reflected in the low grain yields (Tolessa, *et al.,* 2007a).

In 2000 and 2001 the grain yield of CT was similar or lower than the grain yield of either minimum tillage with residue retained (MTRR) or minimum tillage with residue removed (MTRV) (Fig. 1). Interestingly, no significant difference in grain yield was recorded between MTRR and MTRV at all sites during the first two years, except at Bako in 2001. In 2003 and 2004 the grain yield of CT and MTRV was similar at all sites, except at Gudar in 2004. However, for the last two years the grain yield of MTRR was in most instances significantly higher than the grain yield of CT and MTRV. Therefore, when crop residues were removed, it took at least three years before adverse effects on grain yield reductions became evident in the study area. Similarly, when crop residues were retained on the surface, it required at least three years before the beneficial influence on grain yields were obtained. As reported by some researchers (Lal, 1976a; Kang and Yunusa, 1977) grain yield response to minimum tillage when the residues are retained depends on the gradual build-up of soil fertility.

In 2002, 2003 and 2004 when the maize crop faced terminal drought in September and October, MTRR resulted in higher grain yield than both MTRV and CT. This was attributed to the fact that, in drier years, surface crop residues provided a better soil environment by reducing the temperature and conserving water, resulting in better grain filling and hence yield (Tolessa *et al.,* 2007a).

Table 2. Effect of tillage systems on maize grain yield (kg ha^{-1}) in Jimma area (2000–2002).

Tillage	Mana			Nada			
systems	2000	2001	2002	2000	2001	2002	Mean
CT RR	6740	3552	4201	7966	4852	4664	5329
CT RV	6378	2790	4800	8096	4646	4407	5186
NT RR	6231	3696	5327	10397	5527	4545	5953
NT RV	6316	4435	5589	8755	5335	5338	5961
Mean	6416	3618	4979	8804	5090	4739	5607
LSD = 0.05	ns	703	671	862	609	ns	674

CT = conventional tillage, NT = no till, RR = residue retained, RV = residue removed, LSD = least significant difference, ns = not significant

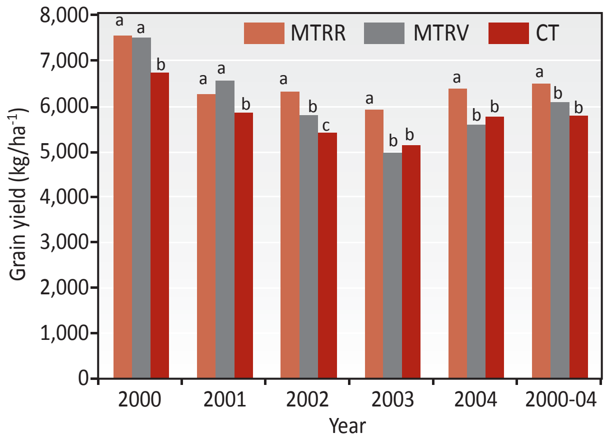

Figure 1. Mean grain yield of maize as affected by tillage systems and crop residue management at Bako. Bars for each year with the same letter are not significantly different at 5% probability. Source: Tolessa *et al.* (2007a). MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage.

Table 1. Rainfall data of Bako Research Center.

	Rainfall (mm)							
	May	June	July	August	September	October	Total cropping season	Total annual
1990–1999	146.1	214.1	254.1	231.7	141.4	70.8	1,058	1,244
2000	135.1	278.2	236.9	289.6	162.0	103.4	1,205	1,346
2001	161.3	219.3	328.9	264.3	96.7	92.7	1,163	1,354
2002	68.3	236.0	239.2	205.9	42.1	0.0	792	1,041
2003	5.7	265.1	420.6	434.4	39.9	11.5	1,177	1,355
2004	14.1	268.6	225.5	257.8	85.2	43.5	895	1,061
2000–2004	76.9	253.4	290.2	290.4	85.2	50.2	1,046	1,231

Nitrogen fertilizer application significantly affected maize grain yield (Fig. 2). In general, a progressive increase in grain yield occurred with incremental levels of N applied. Grain yields were therefore without exception the highest at the 115 kg N ha^{-1} level under all tillage systems. The application of 69 kg N ha^{-1} was significantly inferior to 92 kg N ha^{-1}, and 92 kg N ha^{-1} was on par with the 115 kg N ha^{-1}application. The interaction between tillage system and N fertilization on grain yield was not significant. Thus, the recommended fertilization rate of 92 kg N ha^{-1} for conventional tilled maize seemed also adequate for minimum tilled maize in the study area.

Other researchers reported that under conditions of low soil water and high soil temperature during the growing season, higher grain yields were obtained with minimum tillage where residues were retained and not removed or incorporated with conventional tillage. This phenomenon was attributed to increased water conservation as a result of reduced evaporation (Blevins *et al.*, 1971; Lal 1976a; Phillips *et al.*, 1980), more favorable soil temperatures for root growth (Lal 1974) and microbial processes (Doran, 1980) like soil N mineralization (Rice *et al.*, 1986). Soils prone to water erosion and hence nutrient loss inevitably benefit from minimum tillage that coincides with residue retention as these processes are reduced and therefore higher grain yields result which is not the case with other tillage systems (Triplett and Van Doren, 1977; Phillips *et al.*, 1980; Rasmussen and Collins, 1991). Moreover, it is important to recall that minimum tillage has been proposed as an alternative to conventional tillage to combat erosion (Lal, 1976b; Triplett and Van Doren, 1977; Uri, 1999), to reduce evaporation and enhance the water content in drier environments (Blevins *et al.*, 1971; Phillips *et al.*, 1980; Griffith *et al.*, 1986).

Table 3. Effect of tillage system, residue management and N fertilization on maize grain yield.

N levels (kg ha^{-1})	Tillage system (T)			
	MTRR	MTRV	CT	Mean
69	5,953	5,595	5,210	5,586
92	6,513	6,173	5,868	6,185
115	6,953	6,450	6,227	6,543
Mean	6,471	6,073	5,768	
$LSD_{(0.05)}$	T or N = 394	T × N = ns		

Source: Tolessa *et al.* (2007a). MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage, LSD = least significant difference, ns = not significant.

Effects of tillage system on soil physical and chemical properties

The penetrometer resistance of the Nitisols as measured in the middle of the growing season is displayed in Fig. 3. It is clear that the penetrometer resistance increased with depth irrespective of tillage system. However, penetrometer resistance differed significantly among tillage systems to a depth of 10 cm. In this upper 0–10 cm soil layer, the lowest penetrometer resistance was recorded in the CT soils, followed by the MTRR and then the MTRV soils. Below 15 cm, the penetrometer resistance of the CT soils tended to be slightly higher than that of the MTRV and MTRR soils.

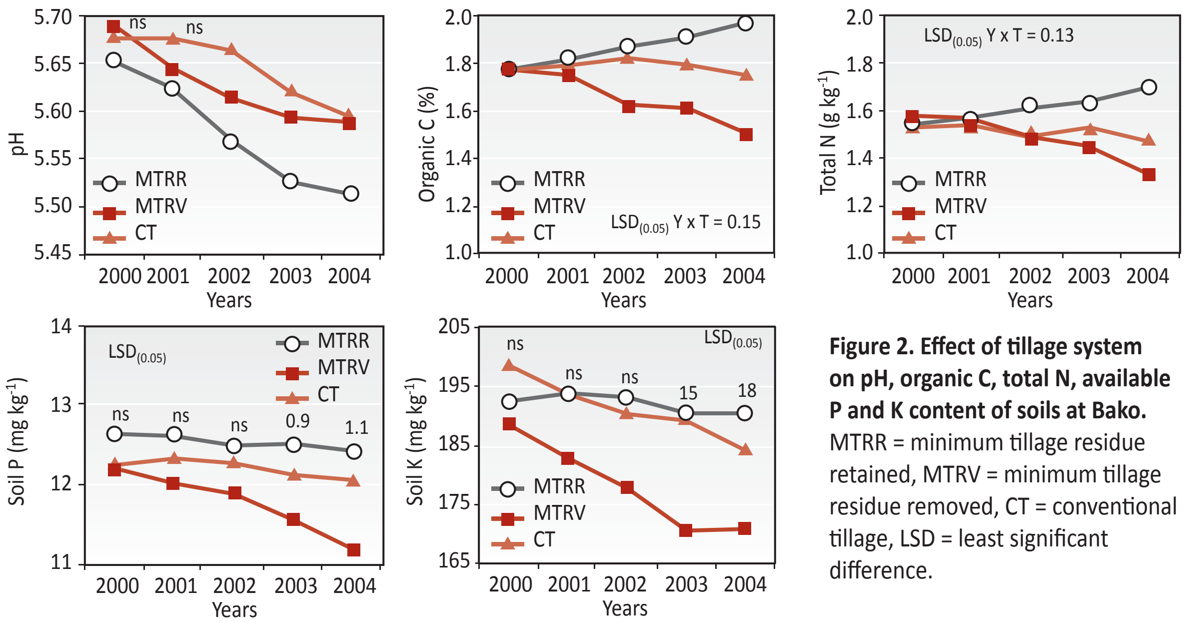

Figure 2. Effect of tillage system on pH, organic C, total N, available P and K content of soils at Bako. MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage, LSD = least significant difference.

Soil analysis indicated that the increase of pH with depth was common in the Nitisols of the study area. However, after five years of the experiments, acidification of the upper 7.5 cm of these soils appeared to be occurring faster with MTRR than with MTRV or CT (Fig. 3). This phenomenon could be attributed to the nitrification of NH_4^+ released from either the fertilizer or residues at or near the soil surface (Blevins *et al.*, 1977; Ismail *et al.,* 1994) since the process produces acidifying hydrogen ions.

Similarly, the application of three tillage systems for five consecutive years on the Nitisols caused tremendous changes of organic C, extractable P and K in the upper 7.5 cm soil layer (Fig. 3). The difference in organic C between MTRR and CT could be attributed to the fact that crop residues and the organic matter were oxidized faster in CT than MTRR soils due to aeration and mechanical manipulation of the soils (Tolessa, 2010).

The higher extractable P levels in the upper 7.5 cm soil layer of the MTRR than the CT soils can be attributed to the applied P fertilizer and the retained maize residues which were not mixed with the soil to the same degree due to the nature of the two tillage systems. The retained maize residues on the soil surface enhanced organic matter formation and in this process some of the P taken up by the crop from deeper layers was

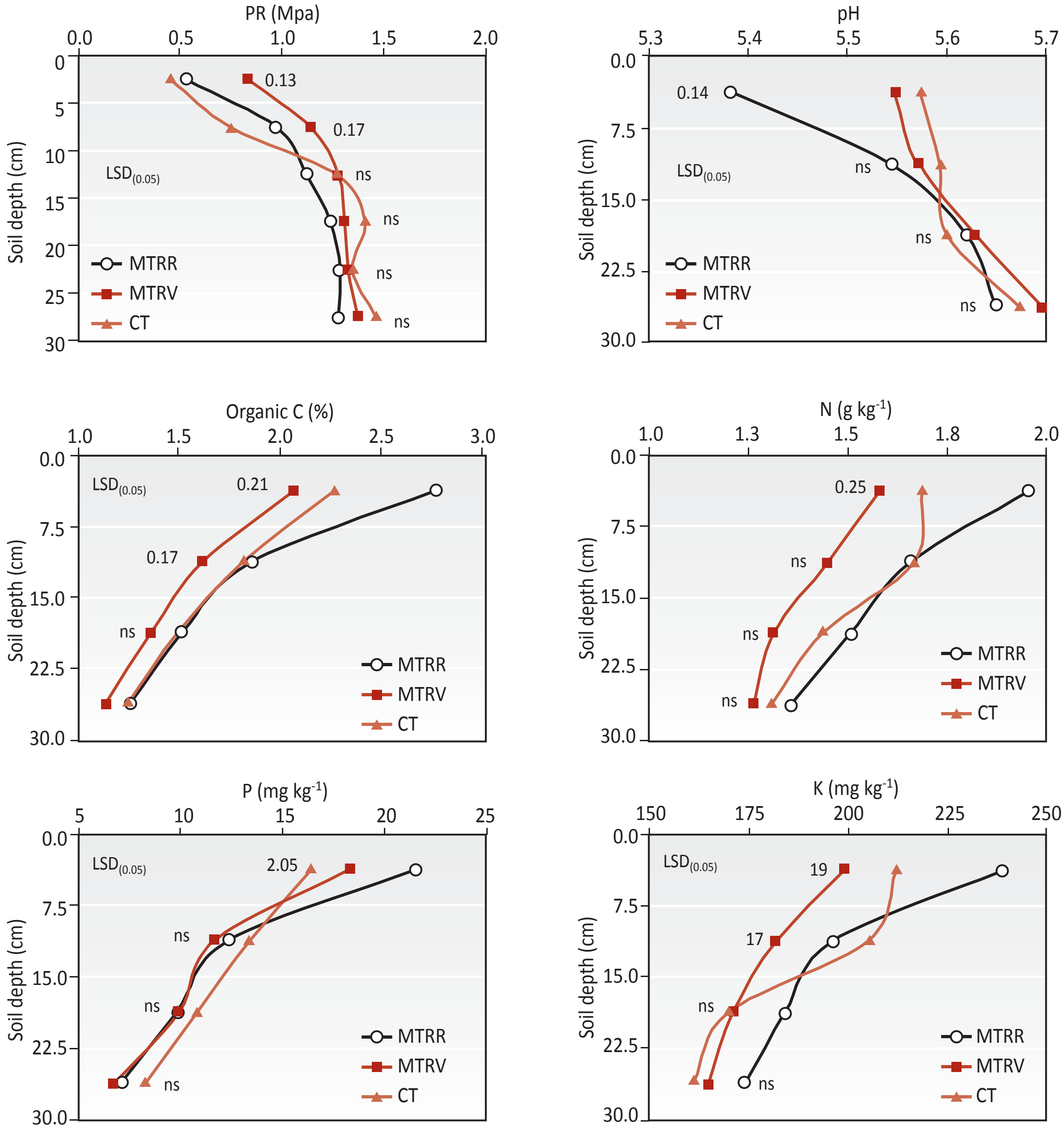

Figure 3. Effects of tillage system and crop residue managements on penetrometer resistance (PR), soil pH, organic C, extractable P and K content of the soil at Bako. MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage, LSD = least significant difference.

released in an inorganic form (Ismail *et al.,* 1994). This released inorganic P is probably less subject to fixation as organic matter can protect it to some degree (El-Baruni and Olsen, 1979). On the other hand, the differences in exchangeable K that evolved in the upper 15 cm of the Nitisols on account of tillage systems are a consequence of the concomitant residue management since no K fertilizer was applied. Fink and Wesley (1974) reported that the fate of maize residues had a large influence on exchangeable K in soils as the residues contain a large amount of K.

Maize N derived from fertilizer and soil

The amounts of grain, stover and total biomass N derived from fertilizer and soil are presented in Table 4. Grain, stover and total biomass N derived from fertilizer were consistently larger with CT than MTRR at all three sites. On average for the MTRR and CT systems 28 vs. 32, 15 vs. 18 and 43 vs. 50 kg ha^{-1} fertilizer N were taken up by the grain, stover and total biomass, respectively. In a similar study with maize Kitur *et al.* (1984) found that fertilizer N uptake by grain, stover and total biomass from MTRR and CT systems amounted to 21 vs. 38, 12 vs. 15 and 33 vs. 53 kg ha^{-1}, respectively.

The grain, stover and total biomass N derived from soil were consistently larger with MTRR than CT at all three sites. On average, for the CT and MTRR systems 33 vs. 49, 23 vs. 28 and 55 vs. 77 kg ha^{-1} soil N were taken up by the grain, stover and total biomass, respectively. Similar results were reported by Reddy and Reddy (1993).

In the case of CT, maize utilized 105 kg N ha^{-1} of which 48% was from the fertilizer and 52% from soil. The contribution of fertilizer was 36% and that of soil 64% for the 120 kg N ha^{-1} utilized by maize in the case of MTRR. These results suggest more mineralization of organic N in the MTRR than CT soils which coincide with the findings of Fox and Bandel (1986). The amount of N mineralized is determined to a large extent by the organic matter content of a soil (Rice *et al.,* 1986). In the longer term, organic matter usually increases in MTRR soils and decreases in CT soils (Lal, 1976a; Blevins *et al.,* 1977; Blevins *et al.,* 1983; White, 1990) as was the case in this study. Furthermore, the differences observed between CT and MTRR with regard to the contribution of soil N to maize may be attributed also to the substitution of ^{15}N for ^{14}N in the soil N pools (Varvel and Peterson, 1990; Rao *et al.,* 1991). This effect would be probably more severe in soils with small N pools than in soils with large N pools.

As shown in Table 5, the NRE of grain, stover and total biomass was consistently larger in CT than MTRR. The maize grown on CT soils at Bako, Tibe and Gudar recovered 59, 55 and 50% of the fertilizer N applied, respectively. Only 50, 48 and 43% of the fertilizer N was recovered by the maize grown on MTRR soils at Bako, Tibe and Gudar, respectively. These values are of the same range as those reported by Kitur *et al.* (1984) and Meisinger *et al.* (1985), viz. 42 to 62% for CT and 36 to 53% for MTRR. The higher recovery of fertilizer N by maize grown on the CT than MTRR soils can be attributed probably to a low N availability in the former soils. A high recovery of fertilizer N by the crop is frequently reported on soils that have a low N availability (Broadbent and Carlton, 1978; Roberts and Janzen, 1990).

Fertilizer N remaining in the soil

The amount of fertilizer N measured in the soil after harvesting of maize at Bako, Tibe and Gudar is given in Table 6. In the case of MTRR, the amount of fertilizer N that remained in the soil up to 90 cm depth varied from 15.5 kg ha^{-1} at Tibe to 17.5 kg ha^{-1} at Gudar with an

Table 4. Effect of tillage system on maize N derived from fertilizer (Ndff) and soil (Ndfs).

Sites	Tillage system	Ndff (kg ha^{-1}) Grain	Stover	Total Biomass	Ndfs (kg ha^{-1}) Grain	Stover	Total Biomass
Bako	MTRR	29.8a	15.9a	45.7a	56.7a	30.6a	87.4a
	CT	34.6b	19.4b	54.0b	36.1b	27.0b	63.1b
Tibe	MTRR	28.4a	15.5a	43.8a	49.9a	29.6a	79.4a
	CT	31.2a	18.9b	50.1b	31.3b	21.3b	52.6b
Gudar	MTRR	25.6a	13.7a	39.2a	41.0a	22.5a	63.6a
	CT	29.7b	16.3b	46.1b	30.4b	19.8a	50.2b

Source: Tolessa *et al.* (2007b). Means within a column for each site followed by same or no letter(s) are not significantly different at P ≤ 0.05. MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage.

Table 5. Effect of tillage system on nitrogen recovery efficiency (%) by maize.

Sites	Tillage system	Grain	Stover	Total biomass
Bako	MTRR	32.4a	17.3a	49.7a
	CT	37.6b	21.0b	58.6b
Tibe	MTRR	30.8	16.8a	47.6a
	CT	33.9	20.6b	54.5b
Gudar	MTRR	27.8a	14.9	42.7a
	CT	32.3b	17.8	50.1b

Source: Tolessa *et al.* (2007b). Means within a column for each site followed by same or no letter(s) are not significantly different at P ≤ 0.05. MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage.

average of 16.2 kg ha^{-1}. Less fertilizer N was recorded to the same depth in the case of CT, viz. from 10.6 kg ha^{-1} at Tibe to 11.1 kg ha^{-1} at Bako and Gudar with an average of 10.9 kg ha^{-1}.

Most of this remaining fertilizer N was detected in the 0–15 cm soil layer, viz. 54% for MTRR and 57% for CT. The contribution of the 15–30 cm soil layer declined to 24% for MTRR and 33% for CT and that of 30–45 cm soil layer to 13% for MTRR and 7% for CT.

Nitrogen balance of applied urea fertilizer

The N balances of the applied urea fertilizer at Bako, Tibe and Gudar are displayed in Table 7. No significant differences were detected among sites and tillage systems for the N balances.

Inspection of Table 7 shows that maize on MTRR soils recovered less fertilizer N than maize on CT soils irrespective of the sites, *viz.* on average 43 vs. 50 kg N ha^{-1}. As a result of this phenomenon more fertilizer N was detected in the MTRR than CT soils regardless of the site, *viz.* on average 16 vs. 11 kg N ha^{-1}. Therefore, the unaccounted fertilizer N in the MTRR and CT systems was almost similar per site, *viz.* on average 33 vs. 31 kg N ha^{-1}. The unaccounted fertilizer N is probably lost through volatilization, leaching or denitrification prior to harvesting.

Nitrogen use efficiencies

Nitrogen agronomic efficiency (NAE)

At every site NAE was higher at the lower N level ranges for the same tillage treatment though not always significant (Table 8). The largest NAE was recorded with CT at the lower N level range and with MTRR at the higher N level range. Bock (1984) and Simonis (1988) reported a higher NAE for maize at lower rather than at higher N application.

In each year, the NAE of CT and MTRV was higher at the lower N level ranges than at the higher ranges. This trend was observed only from 2003 with MTRR. At the lower N level range of the MTRR, NAE differed only in 2002 and 2003 with CT being the superior treatment. However, at the higher N level range, NAE differed every year with the MTRR treatment being superior. The recommended fertilization rate of 92 kg N ha^{-1} for conventional tilled maize is supported by the NAE results. This rate also seems to be sufficient for minimum tilled maize on the Nitisols.

Nitrogen recovery efficiency

The NRE was, with a few exceptions, at every site higher at the lower N level range for the same tillage treatment though not always significant (Table 9). The exceptions were with MTRR at Bako and Tibe where the NRE was almost similar for the two N level ranges.

Table 6. Effect of tillage system on N fertilizer that remained in soil (Nfrs, kg ha^{-1}).

Soil depth (cm)	Bako		Tibe		Gudar	
	MTRR	CT	MTRR	CT	MTRR	CT
0–15	8.7a	6.0a	8.5a	6.2a	9.3a	6.3a
15–30	3.1b	3.8b	3.6b	3.2b	4.7b	3.8b
30–45	1.9c	0.8c	2.3c	1.0c	2.1c	0.7c
45–60	1.0cd	0.3c	0.8d		0.0c	
Total	15.6	11.1	15.5	10.6	17.5	11.1

Source: Tolessa *et al.* (2007b). Means within a column for each site followed by same or no letter(s) are not significantly different at P ≤ 0.05. MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage.

Table 7. Effect of tillage system on the N balance of applied urea fertilizer (kg N ha^{-1}).

Tillage system	Components	Bako	Tibe	Gudar
MTRR	Maize	45.7	43.8	39.2
	Soil	15.6	15.5	17.5
	Unaccounted	30.7	32.7	35.3
CT	Maize	53.9	50.1	46.1
	Soil	11.1	10.6	11.1
	Unaccounted	27.0	31.3	34.8

Source: Tolessa *et al.* (2007b). MTRR = minimum tillage residue retained, CT = conventional tillage.

Table 8. Effect of tillage system on nitrogen agronomic efficiency (kg grain/kg N applied) for different sites, years and N level ranges.

Tillage system	N range (kg ha^{-1})	Sites				
		Bako	Shoboka	Tibe	Ijaji	Gudar
MTRR	69–92	22.6	22.3	20.8	22.7	17.6
MTRV	69–92	24.6	22.0	18.9	22.5	20.7
CT	69–92	26.2	27.1	25.3	25.3	21.3
MTRR	92–115	19.4	16.6	16.7	17.3	13.1
MTRV	92–115	10.5	11.1	10.0	12.7	10.5
CT	92–115	12.6	12.3	13.1	12.2	8.8
$LSD_{(0.05)}$		5.9	7.0	5.8	5.0	6.5
Tillage system	**N range (kg ha^{-1})**	**Years**				
		2000	**2001**	**2002**	**2003**	**2004**
MTRR	69–92	28.6	23.2	15.5	16.5	22.5
MTRV	69–92	30.2	23.6	11.6	22.3	22.1
CT	69–92	29.0	24.3	25.2	23.8	22.9
MTRR	92–115	28.0	22.3	15.6	13.8	16.0
MTRV	92–115	11.4	12.0	5.4	13.0	11.3
CT	92–115	17.6	12.7	14.1	9.7	9.4
$LSD_{(0.05)}$		3.2	3.4	3.9	3.1	4.2

Source: Tolessa *et al.* (2009). MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage, LSD = least significant difference.

At the lower N level range the largest NRE was obtained with CT, followed by MTRV and then MTRR. However, at the higher N level range, the largest NRE was obtained with MTRR, followed by either MTRV or CT. In each year, the NRE of CT and MTRV was higher at the lower N level range than the higher range. This trend was observed only in 2003 with MTRR. The largest NRE was recorded in the majority of years with CT at the lower N level range and with MTRR at the higher N level range.

The NRE varied irrespective of the N level range at all sites from 43 to 51% with MTRR, 30 to 55% with MTRV and 29 to 65% with CT. In all years, regardless of the N level range, the NRE varied from 35 to 56% with MTRR, 27 to 61% with MTRV and from 32 to 62% with CT. These values correspond well with the values reported by other researchers (Legg *et al.*, 1979; Meisinger *et al.*, 1985; Fox and Piekielek, 1993; Staley and Perry, 1995) which varied between 34 and 62% for conventional tillage and between 46 and 76% for minimum tillage.

Nitrogen physiological efficiency

The values for NPE are given in Table 10. At every site NPE was higher at the lower N level range for the same tillage treatment than at the higher range though not always significant. A strong trend exists at both N level ranges of a larger NPE with MTRR than with MTRV and CT.

In each year, NPE was for the same tillage treatment also higher at the lower N level range than at the higher range though not always significant. At both N level ranges, NPE tended to be larger with MTRR than with MTRV and CT.

Therefore, it seems that the translocation of N from the vegetative to reproductive tissue was more efficient in the case of MTRR. This phenomenon can probably be ascribed to a higher availability of water during the grain filling period (Moschler *et al.*, 1972; Bennett *et al.*, 1975; Moschler and Martens, 1975; Phillips *et al.*, 1980).

Table 9. Effect of tillage system on nitrogen recovery efficiency (%) for different sites, years and N level ranges.

Tillage system	N range (kg ha^{-1})	Sites				
		Bako	Shoboka	Tibe	Ijaji	Gudar
MTRR	69–92	48.6	51.1	45.8	50.2	42.9
MTRV	69–92	54.1	55.4	54.0	53.6	51.3
CT	69–92	57.1	63.8	60.5	64.6	56.5
MTRR	92–115	49.1	44.5	45.6	43.0	35.7
MTRV	92–115	29.7	35.8	34.4	35.5	33.1
CT	92–115	38.5	38.5	41.2	36.0	29.0
$LSD_{(0.05)}$		14.9	13.9	12.3	9.6	13.2
Tillage system	**N range (kg ha^{-1})**	**Years**				
		2000	**2001**	**2002**	**2003**	**2004**
MTRR	69–92	50.3	55.1	36.7	40.1	56.4
MTRV	69–92	57.4	57.0	38.6	60.8	54.5
CT	69–92	56.9	62.0	61.5	60.5	61.7
MTRR	92–115	58.3	57.0	41.3	34.5	46.7
MTRV	92–115	31.5	38.9	26.5	36.8	34.8
CT	92–115	40.2	35.6	39.5	31.8	33.2
$LSD_{(0.05)}$		7.3	9.4	8.9	9.1	7.3

Source: Tolessa *et al.* (2009). MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage, LSD = least significant difference.

Table 10. Effect of tillage system on nitrogen physiological efficiency (kg grain/kg N uptake) for different sites, years and N level ranges.

Tillage system	N range (kg ha^{-1})	Sites				
		Bako	Shoboka	Tibe	Ijaji	Gudar
MTRR	69–92	47.0	44.0	45.2	45.3	40.7
MTRV	69–92	45.2	39.5	34.8	42.0	40.0
CT	69–92	46.2	42.6	41.8	39.3	38.0
MTRR	92–115	39.7	36.8	35.9	39.9	36.4
MTRV	92–115	34.6	30.4	29.2	35.2	32.0
CT	92–115	32.9	32.1	31.5	34.5	29.6
$LSD_{(0.05)}$		8.2	10.3	7.6	ns	8.5
Tillage system	**N range (kg ha^{-1})**	**Years**				
		2000	**2001**	**2002**	**2003**	**2004**
MTRR	69–92	56.9	42.2	42.1	40.9	39.9
MTRV	69–92	53.0	41.2	29.9	36.5	40.8
CT	69–92	51.1	39.2	41.1	39.3	37.2
MTRR	92–115	48.3	39.4	38.2	39.8	34.0
MTRV	92–115	36.2	31.4	21.1	35.4	32.4
CT	92–115	44.1	35.3	35.6	30.7	27.9
$LSD_{(0.05)}$		8.9	ns	7.6	ns	6.8

Source: Tolessa *et al.* (2009). MTRR = minimum tillage residue retained, MTRV = minimum tillage residue removed, CT = conventional tillage, LSD = least significant difference, ns = not significant.

Summary

On average, MTRR increased grain yield by 6.6 and 12.2% as compared to MTRV and CT, respectively. MTRR increased maize grain yield particularly when the maize crop faced terminal drought as compared to MTRV and CT. When crop residues were removed, it took at least three years before adverse effects on grain yield reductions became evident and when crop residues were retained on the surface, it required at least three years before the beneficial influence on grain yield was realized.

After five years the influence of the tillage systems on penetrometer resistance, pH, organic C, total N, extractable P and exchangeable K was confined to the upper 0–15cm which is the plow layer. In comparison with CT, MTRR resulted in a higher penetrometer resistance and lower pH which is alarming since both of them should be managed carefully for sustainable cropping. However, MTRR resulted in higher contents of organic C, total N, extractable P and exchangeable K which is reassuring since all of them can be very beneficial to sustainable cropping.

All three indices for efficient use of applied N by maize, *viz.* N agronomic efficiency (NAE), N recovery efficiency (NRE) and N physiological efficiency (NPE) were consistently higher at the lower N level range of 69–92 kg ha^{-1} than at the higher N level range of 92–115 kg ha^{-1}. Both NAE and NRE were higher with CT at the lower N level range and higher with MTRR at the higher N level range. The NPE had a propensity to be higher with MTRR at both N level ranges.

At harvesting, maize recovered on average 47 and 54% of the labeled urea N from the MTRR and CT soils, respectively. Conversely, 12 and 17% of the labeled urea N was still in the CT and MTRR soils at harvesting, respectively. Hence, the unaccounted labeled urea N in the two systems was 36% for MTRR and 34% for CT. Thus, maize farmers in Ethiopia can replace CT with MTRR and sustainably enhance maize production and productivity.

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Review on Crop Management Research for Improved Maize Productivity in Ethiopia

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Introduction

In humid-hot lowlands and tepid mid-altitude agro-ecologies of Ethiopia, maize has a long history of cultivation and has served as a subsistence crop. Currently, its use as a staple food such as green cob, local bread, brews-making in homes and its demand on markets of urban and rural areas are making the crop very popular throughout the country. Traditionally, it is cultivated in many forms of cropping systems such as sole, mixed, intercropping, mono-cropping and in rotation with different crops (McCann, 1995; Tesfa *et al.,* 2002). In low altitudes of western and south-western parts of the country, particularly in Kafa, Bench-Maji, Sheka, Gambella and Beneshangul-Gumuz regions, it is cultivated every season by clearing bushes and sowing soon after burning in non-tilled fields. In these regions, maize is planted year round and seeded manually by putting 2–6 seeds at a point with wide and haphazard spacing. In mid-altitude regions of the south, west and north-west, maize is normally grown in the main rainy season starting from March to November depending on maturity groups and onset of rains for each location. These regions account for more than 80% of the maize production of the country (CSA, 2010). In these areas, as a demand on more land area for maize cultivation has increased, the production of the crop has been maintained at an increasing pace. Although farmers in these regions attempted to use improved crop management practices, continuous cropping on the same piece of land and decreasing fallow periods contributed to the lower productivity of the crop (Tesfa *et al.,* 2004).

In other agro-ecologies of Ethiopia, particularly in the highlands and low moisture-stress regions, maize is another promising crop and is gradually becoming important. In these regions it is an inevitable fact that the number of maize users as well as area coverage is increasing from time to time (CSA, 2010). Though there are some farmers who use small irrigated fields, this crop is mainly grown under rain-fed conditions in both environments (Thorne *et al.,* 2002). In these precarious situations, farmers most often harvest only once in a year those varieties that take a longer period of time on a sole-crop basis. Such traditional practices do not ensure the production of adequate food per household, especially under conditions where the average land holding is very small. Though the area of maize production has been steadily expanding, the aforementioned social and agronomic constraints contribute to low national productivity of the crop, which is nearly 2.3 t ha^{-1} (CSA, 2010).

Therefore, to halt these persistent problems in maize production, there has been a growing interest to improve the productivity of maize through improved agronomic practices. Consequently, some crop management research activities in the area of cultural practices including tillage systems for soil and moisture conservation and cropping systems (intercropping and crop rotation) were carried out with objectives to generate improved crop management methods for various maize producing areas of Ethiopia. Therefore, the objectives of this review are to document agronomic research results during the past decade, to offer recommendations, to suggest research gaps and to propose some future research directions.

Research Achievements

Agronomic studies for increased productivity of maize varieties

Agronomic trials were conducted at various research centers to achieve an increased productivity of some maize varieties that have been recommended for different agro-ecologies of Ethiopia. Accordingly, to enhance grain yield of maize in moisture stress areas, combinations of two moisture conservation techniques (tie ridging and flat tillage), three maize varieties (Melkasa1, ACV6 and A511) and four plant densities (44,444, 53,555, 66,667 and 88,888 plants ha^{-1}) were treated in a split-split plot design with three replications. This trial was conducted at Melkasa and Mieso, representing semi-arid areas of the central rift valley of Ethiopia during 2001 and 2003 cropping seasons. In most cases, tie-ridging that was deemed as the main effect did result in significantly increasing maize grain yield at Mieso and Melkasa in 2001 and 2003, respectively. In the same seasons, due to tie-ridging, a grain yield advantage of 19% over flat tillage was observed at Melkasa, and at Mieso a yield advantage of 37% was obtained from tie-ridging in 2001 (Fig. 1). This study also demonstrated that productivity of maize could be improved by increasing maize plant population density. For Melkasa1 (extra-early maize variety), consistent yield increases were obtained at 66,667 plants ha^{-1} in both years at both locations (Tables 1 and 2). Similarly, for ACV6 (early maize variety) and A511 (intermediate maize variety) significantly higher grain yields were recorded at 53,333 plant ha^{-1} in both locations.

It was generally observed that increasing plant density beyond these population density levels could cause yield reduction for varieties tested at these locations and other similar moisture stress areas of the country. Therefore, this study emphasized the importance of tie-ridging for improved maize productivity by complementing it with optimum plant population densities that could serve for different maturity groups in moisture-stress areas of the country having similar rainfall patterns as Melkasa and Mieso.

Selection of suitable crop varieties in maize intercropping systems

At Metarobi and Adaberga *woredas* of west Shewa zone, three maize varieties (Arganne, Hora and Kuleni) intercropped with three potato varieties (Jalene, Tolcha and Menagesha) were tested on farmers' fields under irrigated conditions in 2005 and 2006 seasons. In these areas, maize was planted in the first week of January in paired rows of 90 × 60 cm apart and potato was planted in between wider rows of maize (90 cm) by maintaining 100% plant population density of maize. A similar trial that consisted of the same varieties was tested at Holetta Research Center under rain-fed conditions in seasons 2005 and 2006 and maize was planted in the first week of May using the same planting method described above. At all sites, potato was intercropped wider rows of maize (90 cm) at 35 days after maize planting. The trials were evaluated in randomized complete block design in three replications. Performance of maize varieties was not significantly affected either by growing periods or the intercropping system. The performance of all potato varieties were significantly affected by growth

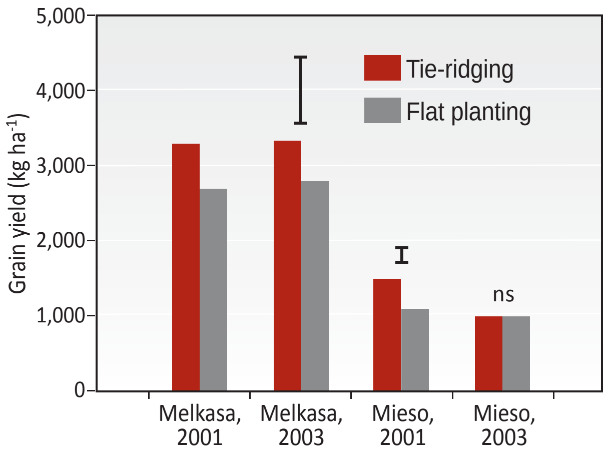

Figure 1. Effect of tillage on the grain yield of maize at Melkasa and Mieso. ns = not significant.

Source: Melkasa Research Center Agronomy Section.

Table 1. Grain yield (kg ha^{-1}) as affected by plant densities and maize varieties at Melkasa.

Density	2001 A511	2001 ACV6	2001 Melkasa1	2003 A511	2003 ACV6	2003 Melkasa1	Density mean yield
44,444	2,615	2,806	2,863	2,438	2,832	3,240	2,799
53,333	2,675	3,309	3,823	2,588	3,169	3,289	3,142
66,667	2,094	3,025	3,793	2,104	3,443	3,547	3,001
88,888	1,962	2,708	2,708	9,685	7,482	3,982	4,755
Variance of the mean	2,337	2,962	3,297	4,204	4,232	3,515	
LSD < 0.05		148			215		

Source: Melkasa Research Center Agronomy Section. LSD = least significant difference.

Table 2. Maize grain yield (kg ha^{-1}) as affected by plant densities and maize varieties at Mieso.

Density	2001 A511	2001 ACV6	2001 Melkasa1	2003 A511	2003 ACV6	2003 Melkasa1	Density mean
44,444	905	1,053	1,999	660	898	1,390	905
53,333	1,100	1,581	1,500	794	1,045	1,673	1,282
66,667	862	1,389	2,172	734	718	2,009	1,314
88,888	844	1,638	2,703	753	784	2,184	1,484
Variance of the mean	928	1,378	1,820	797	863	1,693	
LSD < 0.05	182			174			

Source: Melkasa Research Center Agronomy Section. LSD = least significant difference.

period—all showed better yield performance when grown during the off-season using irrigation. Under the irrigated maize–potato intercropping system, the highest significant ($P \leq 0.05$) maize grain yield was obtained from the maize variety Arganne and the highest potato tuber yield was obtained from the variety Guasa in association with maize variety Hora. However, the lowest grain yield of maize was recorded when Hora was intercropped with a potato variety, Jalane during the off-season (Table 3). Moreover, different potato varieties gave different tuber yield of potato under different maize intercropping systems. Hence, the tuber yield of potato obtained from Hora + Guassa, Kuleni + Guassa, Arganne + Guassa and Kuleni + Jalane was comparable and significantly superior to the rest of potato intercropping treatments. Evaluation based on land equivalent ratio (LER) revealed that Arganne + Guassa, Arganne + Jalane and Kuleni + Jalane gave 30% yield advantage over sole crops. In general, at Holetta, potato production during the off-season in an intercropping system of highland maize varieties using irrigation was found to be very promising, especially with the potato variety Guasa.

Another trial that aimed at evaluating the compatibility of released common bean varieties in a maize intercropping system was carried out on farmers' fields in three districts of the Jimma zone in 2009 and 2010. In intercropping, nine released common bean varieties and two local bean varieties were tested at a 2:1 intra row planting ratio of maize and common bean, respectively, and sole crops of each bean variety were also included for comparisons. Accordingly, among common bean varieties, significant grain yield differences ($P < 0.05$) were recorded in both cropping systems. The performance of maize was not affected by any of the intercropped bean varieties. Three common bean varieties (Brown Scope, Awash1 and Brown Speckled) showed poor growth performance and finally gave the lowest mean grain yield in both cropping systems. On the other hand, Nasir and Dimtu had top growth performance and produced significantly higher mean yield of 2,302 and 2,223 kg ha^{-1}, respectively, in the sole cropping system (Table 4). In the intercropping system, these two varieties exhibited comparable performance to the local varieties. However, the bean variety Roba1 was found to be the most incompatible with maize intercropping systems. Although most varieties had recorded LER of greater than 1.2 and did not show significant differences, the variety Nasir gave the highest LER of 1.5 (Table 4). Thus, two released common bean varieties namely Nasir and Dimtu were confirmed to be best compatible released varieties in a maize intercropping system in the Jimma areas. This study indicates the importance of looking for some other common bean varieties that will have better yield performance and social preferences than current local varieties in maize intercropping systems of Jimma areas.

Planting schedule and pattern in maize intercropping system

At Adamitulu and Siraro, on farm promotion of maize intercropping with common bean at a planting ratio of 2:1 was carried out in seasons 2006 and 2007. Common bean was intercropped in alternate intra rows of maize spaced at 75 × 20 cm and compared to the traditional intercropping system where common beans normally were broadcast in between maize rows of 75 cm. Sole

Table 3. Pooled mean yields (kg ha^{-1}) of maize grain and potato tuber from intercropping system at Holetta.

Maize and potato intercropping	Irrigated/ on-farm		Rain-fed/ on-station		LER
	MGY	PTY	MGY	PTY	
Arganne + Tolcha	6,400	9,270	6,640	3,880	1.1
Arganne + Guasa	6,300	11,950	6,710	5,860	1.3
Hora + Guasa	5,130	14,990	6,390	6,810	1.2
Kuleni + Tolcha	5,670	9,080	6,710	4,230	1.2
Hora + Tolcha	5,300	7,420	6,940	4,590	1.2
Kuleni + Guasa	5,500	10,760	6,170	5,940	1.2
Agranne + Jalane	5,870	11,050	7,220	4,100	1.3
Hora + Jalane	4,270	11,790	6,160	4,110	1.2
Kuleni + Jalane	5,900	7,300	6,530	5,100	1.3
Mean	5,593	10,401	6,608	4,958	1.2
LSD < 0.05	1,700	1,840	620	1,280	0.04

Source: Temesgen *et al.* (2009). MGY = maize grain yield, PTY = potato tuber yield, LER = land equivalent ratio, LSD = least significant difference.

Table 4. On-farm results of land equivalent ratio and grain yields (kg ha^{-1}) of maize and common bean varieties in sole and intercropping systems at Jimma.

Common bean varieties	Sole		Intercropping		LER
	Maize	Bean	Bean	Maize	
Roba1	–	1,552	296	2,764	1.1
Awash1	–	1,030	272	3,070	1.2
Goberasha	–	1,841	584	3,123	1.3
Brown Speckled	–	1,050	318	3,078	1.3
Nasir	–	2,302	742	3,273	1.3
Dimtu	–	2,223	621	3,888	1.5
Brown Scope	–	935	296	3,100	1.3
Local Red	–	1,999	606	3,245	1.3
Local Large Bean	–	1,472	720	2,718	1.3
Sole Maize	3,211	–	–	–	1.0
Mean	3,211	1,600	495	3,140	1.3
LSD < 0.05		327	218	ns	ns

Source: Haramaya University (2009–2010). LSD = least significant difference, ns = not significant, LER = land equivalent ratio.

plant stands of maize variety Melkasa2 and white common bean variety Awash-Melka were also included for comparisons. Results from 2006 showed that the average grain yield of maize decreased to a greater extent under farmers' intercropping practice, contrary to 2007 with the relatively high grain yield reduction of maize under 2:1 intercropping spatial arrangements. The average grain yield of beans in an intercropping system was diminished under farmers' practice due to adverse competitive effect. The land productivity in 2007 was poor with relatively low LER yet it was more advantageous than the sole crop. The substantial reduction in grain yield of beans may be attributed to faster growth of maize at an early stage resulting in a smothering of the beans with low supplemental yield. In both seasons the sole crops gave better yields than intercrops of either maize or common bean. Therefore, results of maize/bean intercropping over the two seasons confirmed that at Siraro, 2:1 planting ratio (maize to bean) had a better LER of 1.1 and at Adamitulu farmers intercropping practice gave a better LER of 1.1 (Table 5). This finding is in accordance with another research report on maize and sorghum intercropping at Haramaya (Tamado and Eshetu, 2000).

Table 5. Mean grain yields of maize and common bean (kg ha^{-1}) and land equivalent ratio of maize + beans intercropping system on the farmers' field at Adamitulu and Siraro.

Cropping systems	Siraro Maize	Siraro Common beans	Siraro LER	Adamitulu Maize	Adamitulu Common beans	Adamitulu LER
2:1 maize/bean intercrop	5,035	573	1.1	5,382	313	1.0
Farmers' intercrop practice	5,243	504	1.1	5,989	208	1.1
Sole maize	6,579	–	1.0	6,093	–	1.0
Sole common bean		1,719	1.0		2,430	1.0

Source: Haramaya University (2006–2007).
LER = land equivalent ratio.

A similar study on maize/bean intercropping with different planting patterns was conducted at Areka on the research station from 1995 to 1997. In the trial, combinations of three intra row spacings for maize (20, 25 and 30 cm) and three intra row spacings (5, 10 and 15 cm) for common bean were evaluated. These had variable plant stand ratios of maize to common bean that were in ranges of 1:1 to 1:5. While a 75 cm inter row space of maize was constantly used for all combinations. Varieties, A511 and Awash1 for maize and haricot bean, respectively, were sown simultaneously and their sole crops were also included for comparisons. Seasonal results showed that grain yields of maize and common bean in the intercropping system were significantly affected by intra row spacing of common bean. At narrower spacing (5 cm) of common bean, its grain yield was significantly increased and maize grain yield was reduced (Table 6). Moreover, a slight increase in maize yield was noticed at wider intra row spaces of common bean. However, due to intra row spacing of maize, the grain yield of any one of these crops was not significantly affected (Table 7). Subsequently, higher LER that ranged from 1.15–1.47 was found from all spacing combinations of maize and common bean in the intercropping systems (Table 6). Thus, highest LER of 1.5 was obtained from 25 and 10 cm intra row spaces of maize and common bean, respectively. Therefore, for efficient land utilization in Areka areas maize and common bean could be intercropped at intra row spaces of 25 cm and 10 cm, respectively.

Table 6. Effect of plant population on grain yield (mean kg ha^{-1}) of maize and haricot bean in intercropping at Areka.

Spacing (cm)		1995		1996		1997		Mean		
Maize	Bean	Maize	Bean	Maize	Bean	Maize	Bean	Maize	Bean	LER
20	5	1,867	222	2,632	321	1,691	221	2,063	255	1.3
20	10	1,928	190	3,090	410	2,091	181	2,370	260	1.4
20	15	2,622	105	3,274	253	2,198	207	2,698	188	1.4
25	5	1,563	284	2,052	433	2,217	315	1,944	344	1.4
25	10	1,983	259	3,484	330	2,024	242	2,497	277	1.5
25	15	1,607	124	3,210	269	2,642	203	2,486	197	1.3
30	5	1,173	253	2,531	378	2,284	325	1,996	319	1.4
30	10	1,743	161	1,995	361	1,844	179	1,861	234	1.2
30	15	1,847	135	3,187	410	2,345	167	2,476	238	1.4
Mean		1,820	193a	2,828	352ab	2,148	227b			
Sole crops		1,753	586	3,407	561	3,296	275	2,819	474	

Source: Hawassa Agricultural Research Center (1995–1999), LER = land equivalent ratio. Mean bean yields followed by same letters are not significantly different at $P \leq 0.05$

Another intercropping trial that sought to select an appropriate planting pattern of maize to bean rows was conducted at Hawassa from season 1998 to 2000. Single and double alternate bean rows were intercropped in the inter rows of maize and for comparison sole crops of maize and bean were also included in the treatments. Accordingly, single alternate rows gave significantly higher grain yields of both component crops and yield advantage of 19% over the double row arrangement (Table 8). Thus, results over the three years confirmed a better land use advantage of 66% and 31% due to single and double alternate rows of bean, respectively, in maize/bean intercropping systems. Therefore, it was concluded that alternate single bean rows in maize intercropping would be more productive and economical than sole stands of either maize or bean at Hawassa.

Crop rotations and improved fallows

Uses of grain legumes and oil crops

A study conducted at Bako using *noug* as the preceding crop indicated that maize grain yields were significantly increased in rotation with this crop compared to the continuously cropped maize (Table 9). This result clearly demonstrated the residual benefits of crop rotation with reduced nitrogen-phosphorus (NP) fertilizer amendments and enhanced maize grain yield. Also, the integrated use of precursor crops with low rates of NP and farmyard manure (FYM) gave comparable maize grain yield with a plot that received the recommended fertilizer rate (110/20 kg NP ha^{-1}). Production of maize following *noug* as a precursor crop by integrating with 46/5 kg ha^{-1} N/P and 8 t FYM ha^{-1} could be affordable for smallholder farmers in the Bako areas.

Another trial on rotation of common bean in sole and intercropping systems with maize at Bako demonstrated that maize planted following sole planted common bean gave a higher mean grain yield and was economically profitable as compared to maize produced following intercropped haricot bean or continuous maize (Table 10). Therefore, maize production following sole common bean with the recommended fertilizer could be another alternative for sustainable maize production in the Bako area. A crop rotation study on maize rotated with soybean in four districts of Jimma zone showed a 26–46% improvement in maize grain yield whenever rotated on a previous soybean field (Table 11). It was also found that soybean contributed 46 kg ha^{-1} urea to succeeding maize crops and thus, it could offset the cost of 46 kg ha^{-1} urea for smallholder farmers (Table 12). Maize rotated on soybean fields with a lower fertilizer rate had the highest value cost ratio (VCR) of 13.

Table 7. Mean grain yields (kg ha^{-1}) of intercropped maize and common bean as affected by intra row spacing.

Maize spacing (cm)	Maize yield	Bean yield	Bean spacing (cm)	Maize yield	Bean yield
20	2,378	237	5	2,000	305a
25	2,311	274	10	2,244	257ab
30	2,104	267	15	2,548	208b
LSD < 0.05	**Maize spacing (cm)**	**Bean spacing (cm)**	**Year**	**Interaction (all)**	
Maize	NS	NS	**	NS	
Bean	NS	**	**	NS	

Source: Hawassa Agricultural Research Centre (1995–1999). Bean yields followed by same letters are not significantly different at P ≤ 0.05, LSD = least significant difference, NS = not significant, * = significant at P ≤ 0.05, ** = significant at P ≤ 0.01.

Table 8. Evaluation of maize intercropping with common bean at two planting patterns at Hawassa.

	Maize grain yield	Bean grain yield	LER
Sole maize	4,366	–	1.0
Sole common bean	–	1,337	1.0
Single alternate row (1MZ:1CB)	3,720	1,089	1.7
Double alternate row (1MZ:2CB)	3,116	804	1.3
Mean	3,734	1,077	

Source: Hawassa Agricultural Research Center (1995–1999). LER = land equivalent ratio.

Table 9. Effects of precursor crops, nitrogen-phosphorus (NP) and farmyard manure (FYM) fertilizer rate on grain yield of maize at Bako.

Precursor crop	N/P kg ha^{-1} + FYM t ha^{-1}	Grain yield (kg ha^{-1}) 2002	2003	Mean
Noug	23/5 + 4	7,815	6,833	7,324
Noug	23/5 + 8	7,968	6,726	7,347
Noug	23/10 + 4	7,723	6,675	7,199
Noug	23/10 + 8	8,383	8,040	8,211
Noug	46/5 + 4	8,138	7,440	7,789
Noug	46/5 + 8	9,226	8,705	8,965
Noug	46/10 + 4	6,585	7,310	6,947
Noug	46/10 + 8	8,859	8,046	8,453
Continuous maize	110/20 + 0	9,639	7,467	8,553
LSD <0.05		ns	1,142	1,069

Source: Bako Agricultural Research Center (unpublished data). LSD = least significant difference, ns = not significant.

Table 10. Effects of common bean rotations and N/P fertilizer rate on grain yield of succeeded maize.

Treatment Crops (2004)	Maize with N/P_2O_5 kg ha^{-1}	Grain yield (kg ha^{-1}) 2005	2006	Mean
M/BB	M-59/23	5,950	4,254	5,102
M/BB	M-89/35	6,484	3,897	5,191
M/BB	M-110/46	6,935	5,777	6,356
BB	M-59/23	8,691	5,872	7,281
BB	M-89/35	8,571	5,841	7,206
BB	M-110/46	9,550	6,052	7,801
M/CB	M-59/23	5,055	4,429	4,742
M/CB	M-89/35	6,278	5,508	5,893
M/CB	M-110/46	7,797	5,686	6,742
CB	M-59/23	8,457	4,517	6,487
CB	M-89/35	9,240	5,733	7,486
CB	M-110/46	10,148	6,066	8,107
M	M-110/46	7,314	6,123	6,718
LSD < 0.05		2,374	1,879	1,484

Source: Bako Agricultural Research Center (unpublished data). M/BB = maize/bush bean intercropping, BB = sole bush bean, M/CB = maize/climbing bean intercropping, CB = sole climbing bean, M = sole maize, LSD = least significant difference.

Table 11. Soybean rotation effects on subsequent maize grain yield at Jimma.

Crops in rotation + N-Levels	Seasons 2003	2004	Rotation mean	% increase
	Maize grain yield (kg ha^{-1})			
CMZF + 18 kg N ha^{-1}	3,013	4,693	3,853c	–
CMZF + 64 kg N ha^{-1}	4,077	5,628	4,852b	26
PSYF + 18 kg N ha^{-1}	4,417	5,298	4,857b	26
PSYF + 64 kg N ha^{-1}	5,109	6,185	5,647a	46
Season mean	4,154b	5,451a		

Source: Tesfa *et al*. (2009), PSYF = previous soybean field, CMZF = continuous maize field. Season means followed by same letters are not significantly different at P ≤ 0.05.

Table 12. Economic benefits of soybean rotation to subsequent maize.

Crops in Rotation + N-Levels	Maize grain yield (kg ha^{-1})	Gross return ETB ha^{-1}	Net benefit ETB ha^{-1}	VCR
CMZF + 18 kg N ha^{-1}	3,853	3,467.7	3,162.70	10
CMZF + 64 kg N ha^{-1}	4,852	4,366.8	3,789.89	7
PSYF + 18 kg N ha^{-1}	4,857	4,371.3	4,066.30	13
PSYF + 64 kg N ha^{-1}	5,647	5,082.3	4,505.30	8

Source: Tesfa *et al.* (2009). PSYF = previous soybean field, CMZF = continuous maize field, ETB 8.67 = US$ 1.00 (at time experiment was conducted), MRRI = marginal rate of return on investment, VCR = value cost ratio.

Legumes for short fallows and green manuring

Among green manure legumes, *Dolichose lablab, Mucuna pruriens, Crotalaria ochralueca* and *Sesbania sesban* have been adapted in Bako and Jimma areas for enhancement of soil fertility (Dennis *et al*., 2003). Subsequent research efforts showed that from maize planted on previous sole green manure legume fields, grain yield increases of 30–40% were obtained over plots that received optimum N-fertilizer from external sources (Table 13). Thus, it was realized that green manure of sole legumes had the potential to substitute more than 70 kg N ha^{-1} from urea. On the other hand, maize planted on previous plots of intercropped legumes with integration of one-half N from the recommended rate showed grain yield increases of 10–20% over continuous maize plots that received the same N-rate (Table 14). This also implied that green manure of intercropped legumes could at least offset the cost of 46 kg N ha^{-1} from urea for smallholder farmers. Therefore, two options were set as to how to utilize these legumes in maize-based farming systems. Option number one for farmers having sufficient land, was a sole legume could be grown and the maize subsequently planted would not require additional N from external sources. Option number two for those farmers who do not have sufficient land was either *Mucuna pruriens* or *Crotalaria ochralueca* could be intercropped in between maize rows 4 weeks after maize emergence as a preceding crop and maize could be planted with application of one-half N recommended from external sources. Therefore, advice should be given to maize producers that; smallholders can sustain maize production in humid areas through the inclusion of legumes as a green manuring.

Integrated management of legume fallows with FYM and NP fertilizer

At Bako integrated use of improved fallow of *Mucuna* [*Mucuna pruriens* (L) DC] with NP fertilizers enhanced soil chemical properties, mainly soil pH, basic cations and reduced exchangeable acidity and increased uptake of nitrogen, phosphorus, and potassium in maize (Wakene *et al.,* 2007). The integrated use of these organic sources with inorganic fertilizers significantly improved maize grain yield over the control and recommended rate of inorganic fertilizers (Table 15). During three cropping seasons (2001–2003) the use of a short fallow of *Mucuna* alone increased maize grain yield by 111% over the control. Therefore, short fallowing of *Mucuna* along with 4 t ha^{-1} FYM or with one-half dose of the recommended NP fertilizers could be used as a low cost intermediate technology for enhancing soil fertility and increasing maize yield and also guaranteeing sustainable maize production in western Ethiopia.

Fertilizer requirements in maize intercropping systems

A field experiment that aimed at studying the effects of phosphorus, nitrogen and rhizobium application on grain yields of common bean and maize under an intercropping system was conducted at Haramaya at Rare experimental field from seasons 2001 to 2003. Combinations of four levels of N (0, 20, 40 and 60 kg N ha^{-1}), three levels of P (0, 10 and 20 kg P ha^{-1}) and two levels of rhizobium inoculants (uninoculated and inoculated) were used. A maize variety, Rare1 was planted in rows at 0.75 m × 0.40 m spacing and two bean seeds of variety M142 were sown in intra rows spaced at 0.15 m from each maize stand and beans 0.10 m from each other. The inoculated treatment

Table 13. Biomass and grain yields of maize subsequently planted on previous fields of sole and intercropped legumes: on-station.

Treatment	Maize biomass yield (t ha^{-1})		Mean biomass yield (t ha^{-1})	Maize grain yield (t ha^{-1})		Mean grain yield (t ha^{-1})
	2001	2002		2001	2002	
Mz + Muc ITEVS	5.4	10.6	8.0de	1.6	4.0	2.8c
Mz + Muc ITFS	6.4	9.9	8.2de	2.4	3.8	3.1c
Mz + Cav ITEVS	8.0	10.9	9.5cd	2.3	2.3	3.3c
Mz + Cav ITFS	6.0	9.6	7.8e	1.9	3.6	2.8c
Mz + Crt ITEVS	7.5	10.5	9.0cd	2.2	4.3	3.3c
Mz + Crt ITFS	6.3	10.2	8.2de	2.0	4.1	3.0c
Sole Mucuna	9.5	14.9	12.2b	2.9	6.0	4.4b
Sole Canavalia	10.3	14.1	12.2b	3.9	6.6	5.2a
Sole Crotalaria	11.9	17.4	14.6a	4.6	6.9	5.7a
CSMz + 69 kg N ha^{-1}	8.7	12.2	10.5c	3.2	4.9	4.0b
CSMz + 0 kg N ha^{-1}	7.9	12.2	10.1c	2.0	4.2	3.1c
Mean	8.0b	12.1a		2.6b	4.9a	

Source: Tesfa *et al.* (2004). Mz = maize, CSMz = continuous sole maize, Muc = *Mucuna*, Cav = *Canavalia*, Crt = *Crotalaria*, ITEVS = intercropped at early vegetative stage, ITFS = intercropped at flowering stage. Mean yields followed by same letters are not significantly different at P ≤ 0.05.

Table 14. Biomass and grain yield of maize subsequently planted on previous fields of intercropped legumes: on-farm.

Treatment	Biomass yield (t ha^{-1})		Mean biomass yield (t ha^{-1})	Grain yield (t ha^{-1})		Mean grain yield (t ha^{-1})
	46 kg N ha^{-1}	92 kg N ha^{-1}		46 kg N ha^{-1}	92 kg N ha^{-1}	
Mz + Crt ITEVS	11.1	12.5	11.8a	5.5	6.4	6.0a
Mz + Muc ITEVS	12.1	12.6	12.4a	6.1	6.1	6.1a
CSMz	10.7	11.6	11.1b	5.2	5.8	5.5b
Mean	11.3b	12.2a		5.6b	6.1a	

Source: Dennis *et al.* (2003). Mz = maize, CSMz = continuous sole maize, Muc = *Mucuna*, Crt = *Crotalaria*, ITEVS = intercropped at early vegetative stage, ITFS = intercropped at flowering stage. Mean yields followed by same letters are not significantly different at P ≤ 0.05.

Table 15. Effects of integrated management of *Mucuna* short fallow with NP fertilizer on plant height and maize grain yield at Bako.

Treatment	Plant height (cm)				Grain yield (t ha^{-1})			
	2001	2002	2003	Mean	2001	2002	2003	Mean
Control	250	277	201	242	2.3	2.7	1.7	2.2
IF	295	312	248	285	4.0	4.3	5.9	4.7
IF +55/10 NP	347	304	269	311	7.9	4.0	5.8	5.9
IF +37/7 NP	339	319	248	297	7.7	3.8	5.9	5.8
IF + 4 t ha^{-1} FYM	340	317	274	312	7.4	4.9	6.4	6.3
IF + 2.7 t ha^{-1} FYM	341	318	270	309	6.3	4.3	7.3	6.1
110/20 kg h^{-1} NP	336	318	251	301	5.5	3.3	4.5	4.4
LSD <0.05	39.3	ns	34.8	18.9	1.4	ns	1.8	0.9

Source: Wakene *et al.* (2007). IF = improved fallow with *Mucuna* green manure, FYM = farmyard manure, LSD = least significant difference, ns = not significant showed significant increase of nodule weight over the uninoculated treatment (Table 16). Though the lowest dose of N produced the highest nodule weight, increasing the dose of N beyond 20 kg ha^{-1} tended to reduce nodule weights. Conversely, the increased doses of P gave increments in the weights of nodules. The seed yield of beans showed an increasing trend, as the rate of combinations increased, indicating that optimum combinations of N and P are essential to boost seed yield of beans when intercropped with maize (Table 17). Thus, in line with inoculation, significant interactions among doses of N and P were observed. Similarly, the interaction of N and P recorded maximum grain yield (3,926 kg ha^{-1}) of maize at 60/20 kg ha^{-1} NP (Table 18). Therefore, whenever maize is intercropped with common beans, 60/20 kg ha^{-1} NP can be used on Rare1 but verifications are advised to have justifiable recommendation for further use on surrounding farmers' field.

Table 16. Fresh nodule weight (g plant^{-1}) of common bean influenced by phosphorus, nitrogen and rhizobium application in intercropping system with maize in 2001–2003.

Phosphorus (kg ha^{-1})	Rhizobium	Nitrogen (kg ha^{-1}) 0	20	40	60	Mean
0	Inoculated	700	1351	710	585	837
	Uninoculated	620	600	636	480	584
10	Inoculated	1225	1210	705	625	941
	Uninoculated	624	715	710	600	662
20	Inoculated	790	1380	980	655	951
	Uninoculated	634	750	698	590	668
Mean	Inoculated	905	1314	798	622	
	Uninoculated	626	688	681	557	

Source: Haramaya University (2001–2003).

Table 17. Grain yield (kg ha^{-1}) of common bean influenced by phosphorus, nitrogen and rhizobium application in intercropping system with maize in 2001–2003.

Phosphorus (kg ha^{-1})	Rhizobium	Nitrogen (kg ha^{-1}) 0	20	40	60	Mean
0	Inoculated	498	560	550	540	537
	Uninoculated	367	405	395	370	384
10	Inoculated	540	515	600	545	575
	Uninoculated	394	457	435	420	427
20	Inoculated	555	660	595	560	593
	Uninoculated	410	500	460	445	454
Mean	Inoculated	531	612	582	548	
	Uninoculated	390	454	430	412	

Source: Haramaya University (2001–2003).

Conclusions and Recommendations

Subsequent studies on combinations of planting density of three maize varieties and tillage methods for moisture conservation at Melkasa and Mieso demonstrated the importance of tie-ridging for improved maize productivity and thus suggested that it could be used in other moisture stress areas having similar rainfall patterns in the country. Optimum plant densities of 66,667 and 53,333 plants per hectare were found for extra-early (Melkasa1) and early to intermediate maize varieties (ACV6 and A511), respectively. Evaluation of intercropped potato varieties at Holetta confirmed that potato production during the off-season in an intercropping system of highland maize varieties by using irrigation was very promising and among potato varieties Guasa was the most compatible system. A similar study executed at Jimma showed that most released bean varieties tested in maize intercropping system recorded LER of greater than 1.2 and among the varieties, Nasir and Dimtu were identified as the best system-compatible. Likewise, different planting patterns of maize with bean intercropping systems at various locations confirmed that a 2:1 planting ratio (maize to bean) had better land use advantages for smallholder farmers.

At Bako, maize planted following *noug* integrating it with 46/5 kg ha^{-1} N/P and 8 t FYM ha^{-1} could be affordable for smallholder farmers in Bako areas. At Jimma also, maize rotated with soybean on farmers' fields gave up to a 46% grain yield advantage and further it was found that soybean contributed 46 kg N ha^{-1} to succeeding maize, and thus, it could offset the cost of 46 kg N ha^{-1} from commercial urea for smallholder farmers. At Jimma, green manure

Table 18. Grain yield (kg ha^{-1}) of maize influenced by phosphorus, nitrogen and rhizobium application in intercropping system with common bean in 2001–2003.

Phosphorus (kg ha^{-1})	Rhizobium	Nitrogen (kg ha^{-1}) 0	20	40	60	Mean
0	Inoculated	2,550	2,588	2,684	3,415	2,809
	Uninoculated	2,285	2,128	2,299	2,845	2,539
10	Inoculated	2,646	3,000	3,430	3,500	3,144
	Uninoculated	2,450	2,555	2,938	2,941	2,721
20	Inoculated	2,880	3,250	3,448	3,926	3,376
	Uninoculated	2,710	2,802	2,835	2,950	2,824
Mean	Inoculated	2,692	2,946	3,187	3,613	
	Uninoculated	2,482	2,695	2,691	2,912	

Source: Haramaya University (2001–2003)

legumes such as *Dolichose lablab, Mucuna pruriens, Crotalaria ochralueca* and *Sesbania sesban* enhanced soil fertility and resulted in grain yield increases of 30–40% over plots that received an optimum mineral N-fertilizer from a urea source and further realized that green manure of sole legumes had potential to substitute for more than 70 kg urea N ha^{-1}. At the same location maize planted on previous plots of intercropped legumes with integration of one-half recommended N rate recorded grain yield increases of 10–20% over continuous maize plots that received the same N-rate. At Bako, integrated uses of short fallows of *Mucuna* along with 4 t ha^{-1} FYM or with one-half dose of the recommended NP fertilizers produced better maize grain yield.

At Haramaya, inoculation of common bean intercropped with maize, coupled with applying varying NP fertilizer rates, revealed that at the lowest dose of N, higher nodule weights were obtained. It was further found that increasing doses of N beyond 20 kg ha^{-1} tended to suppress nodule weights. Conversely, the increased doses of P gave increases in nodule weights. Moreover, for maize intercropped with common beans, 60/20 kg ha^{-1} N/P was determined as the optimum rate to obtain maximum yields of both component crops around Haramaya.

Generally, it could be concluded that tie-ridging is a critical technology for better moisture conservation and for producing increased maize grain yield in moisture stress regions of Ethiopia. In maize/bean intercropping systems identification of the best system-compatible bean variety is an indispensable study. Crop rotations and use of green manure are low cost and intermediate technologies for enhancing soil fertility that could increase maize grain yields and guarantee sustainable maize production in Ethiopia.

Research Gaps and Future Directions

Research gaps

- To offer reliable recommendations, evaluation of crop rotations, legume fallows and green manures on farmers' fields is required.
- Work on selection of grain legumes suitable for rotation in line with compatible rhizobia inoculums in maize-based farming systems has been given little attention in different soil types and agro-ecologies.
- Insufficient studies have been made on rhizobia inoculation of common beans intercropped with maize in different agro-ecologies of Ethiopia.
- Compatibility study of common bean varieties in maize intercropping systems and their adaptation to various soil types and agro-ecologies is not yet well addressed.
- Research on farmers' perception or social assessments on maize crop rotation with legumes and uses of organic fertilizer sources (FYM, green manure and short legume fallows) were overlooked and most results did not include their economic feasibility.
- Despite research outputs of tillage practices (tie-ridge) at different research institutions, little effort have been made to promote them on smallholder farmers' fields.

Future research directions

- On-farm evaluation of crop rotations, legume fallows and green manures should be done in various maize growing regions in a well-coordinated manner to offer reliable recommendations.
- Due attention should be given to the selection of grain legumes suitable for rotation in line with compatible rhizobia inoculums in maize-based farming systems in different soil types and agro-ecologies.
- Studies of rhizobia inoculation of common beans intercropped with maize in different agro-ecologies of Ethiopia should be emphasized.
- Continuous and well-coordinated research on the compatibility of common bean varieties in maize intercropping systems and their adaptation to various soil types and agro-ecologies should be initiated.
- Research on farmers' perception or social assessments and economic feasibility of maize crop rotation with legumes and uses of organic fertilizer sources (FYM, green manure and short legume fallows) should be initiated and coordinated work must be carried out.
- Coordinated efforts of different stakeholders should be solicited to promote research output of tillage practices (tie-ridge) on smallholder farmers' fields in moisture stress areas of Ethiopia.

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Towards Sustainable Intensification of Maize–Legume Cropping Systems in Ethiopia

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Introduction

Food security is a major concern in the eastern and southern African region. Urban food price within the region is extremely high, aggravating food insecurity among subsistence urban households. Among the food crops, maize is the main staple (Bänziger and Diallo, 2004), and legumes are an important dietary protein source for the rural poor (Onwueme and Sinha, 1991). In eastern and southern Africa, the demand for maize is projected to increase by at least 40% over the next ten years; and the demand for legumes by 50% (FAOSTAT, 2010). However, seasonal variability causes wide swings in food crop yields, including maize and legumes. Rain-fed maize–legume cropping systems show considerable promise in boosting productivity and helping reverse the decline in soil fertility that is a fundamental cause of low smallholder productivity in eastern and southern African region.

Maize and grain legumes co-exist in all maize agro-ecologies of Ethiopia. Most maize-growing areas in the country can be regarded as maize–legume based farming systems; the difference lies in the maize varieties and legume species grown. Grain legumes are planted in intercrops, alleys and rotations with maize in mid-altitude sub-humid (common beans and soybean), highlands (faba bean and chickpea), dry land (common bean, pigeon pea, cowpea and groundnut) and low-altitude sub-humid (cowpea) ecologies.

The Sustainable Intensification of Maize–Legume based cropping systems for Food Security in Eastern and Southern Africa (SIMLESA) project was launched in Ethiopia in March 2010. The overall objective of this project is to increase food security and incomes at household and regional levels, and contribute to the economic development of the country through improved productivity from more resilient and sustainable maize-based farming systems. The project which has CIMMYT as the executing agency is funded by the Australian Center for International Agricultural Research (ACIAR) and implemented in Australia and Eastern and Southern African countries (Ethiopia, Kenya, Tanzania, Mozambique, and Malawi). It is designed to fit the regional and national agricultural development priorities of the target countries. It aims at increasing farm-level food security and productivity, in the context of climate risk and change. It promotes conservation agriculture (CA)-based maize–legume integration to result in resilient, profitable and sustainable farming systems that overcome food insecurity for significant numbers of farm families. This paper presents the key achievements of the project in Ethiopia since its inception.

Major Activities Undertaken

Identification of target research communities

The current activities were undertaken in two maize–legume based farming systems classified broadly as the mid-altitude dry land zone in the rift valley and the mid-attitude sub-humid zone in western Ethiopia. In the dry land zone, moisture stress (drought) is the main limiting factor for crops and livestock production because rainfall is erratic and insufficient, a situation aggravated by high evapotranspiration rates. Irrigation and water harvesting techniques and technologies for the efficient use of the limited rainfall are poorly developed.

The activities in the drought-prone areas of the rift valley region of Ethiopia were conducted by researchers from Melkasa Agricultural Research Center (MARC) and Hawassa Agricultural Research Center (HARC) while the activities in the sub-humid, high potential maize growing areas of the country were conducted by the researchers from Bako Agricultural Research Center (BARC) and Pawe Agricultural Research Center (PARC). To identify specific research communities in the vicinity of each research center, a group of researchers consisting of breeders, agronomists, agricultural economists and extension workers, and technicians from each SIMLESA implementing research center made exploratory visits to the target project areas in both the drought prone rift valley and the high potential maize growing agro-ecologies and selected target project communities for each research centre.

As indicated in Fig. 1, in the drought-stress rift valley, the Melkasa team targeted five communities each in Boset, Sire, Dugda, Adami-Tullu and Shalla while the Hawassa team selected three communities each in Hawassa-Zuria, Meskan and Badawacho districts. In the high potential maize growing agro-ecology, the Bako team identified two target communities each from Gobu-Sayo and Bako-Tibe districts. Similarly, PARC selected two communities each from Pawe and Guangua districts. The farming systems in both target areas consisted of mixed crop-livestock systems. The selection was based on the criteria of road accessibility for monitoring of the trials and importance of the two crops in the communities.

Identification of options for systems intensification and diversification

Potential, sustainable, risk reducing and more productive best-bet technology options that contribute to the sustainable increase of maize system productivity and legume options for system diversification were identified. Accordingly, an open-pollinated variety (OPV; Melkasa2), a legume variety (Nasir) and CA practices (no till, residue management, maize-legume intercropping and rotations) were selected by MARC for on-farm exploratory trials. HARC also identified one hybrid maize variety (BH543) and one common bean variety (Awassa Dumme) and maize–bean intercropping practices with different population densities for the same activity. Maize (BH543), common bean (Anger) and soybean (Dedessa) varieties and CA technologies (maize–legume intercropping and rotation) were selected by BARC to conduct integrated CA based on-farm exploratory trials. PARC used one popular hybrid maize variety for the area, BH540, and one soybean variety (Belessa95) and CA technologies (maize–legume intercropping and rotation) for the exploratory trial. These best-bet options were integrated in various forms and evaluated in on-station and on-farm trials.

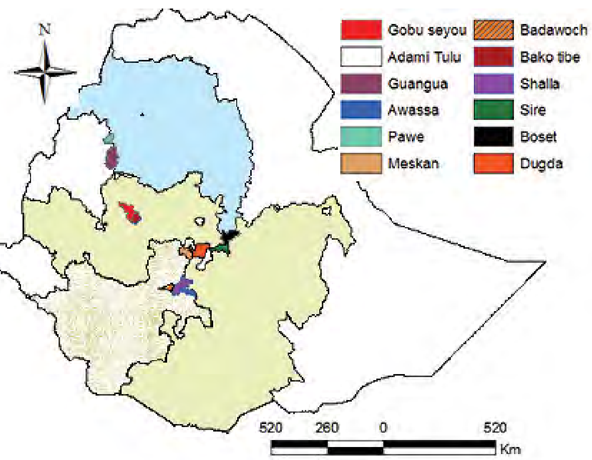

Figure 1. Target districts of the Sustainable Intensification of Maize–Legume based cropping systems for Food Security in Eastern and Southern Africa SIMLESA project in Ethiopia.
NB. Currently Hawassa is the official name for Awassa.

On-station evaluation of best-bet options under representative agro-ecologies

Prior to preparing the trials, soil properties of the trial sites in each research center were characterized. The MARC experimental field had a dominantly loam and clay loam texture. Available soil water lies between 34.0% at field capacity and 16.7% at permanent wilting point on dry weight basis. The average bulk density at a depth of 0–90 cm was 1.13 g cm^{-3}. The soil is slightly alkaline as pH in water ranged from 7.4–7.6, an optimum range for availability of major nutrients. BARC soil was classified as sandy clay loam at 0–20 cm and sandy clay at both 20–40 cm and 40–60 cm depths. The total N was 0.1% at a depth of 0–20 cm and dropped gradually to about 0.1% at 40–60 cm soil depth. Organic carbon content dropped from 1.8% at 0–20 cm depth to 1.2% and 0.2% at depths of 20–40 cm and 40–60 cm, respectively. Available soil P was 8.0 ppm at 0–20 cm depth and then dropped to zero at depths of 20–40 cm and 40–60 cm. The soils at Pawe were broadly categorized as Vertisols, which accounted for 40–45% of the area, Nitisols, which accounted for 25–30%; and intermediate soils of a blackish brown color, which accounted for 25–30%.

The on-station trials conducted at the three research centers (MARC, BARC, and PARC) consisted of three treatments including sole maize and legume, intercropping (maize–legume), and rotation (legume–maize) both under conventional practice (CP) and CA management laid out as randomized complete block design (RCBD) in split-plot arrangement whereby tillage practices (CP vs. CA) were used as main plots and all cropping systems (sole, intercropping and rotation) were used as sub-plots. The trials were sown in plot sizes of more than 100 m^2 following the recommended row and plant-to-plant spacing of respective localities. During data collection the outermost rows at both sides of the plots and 0.5 m row length at each end of the rows were considered as borders. Recommended fertilizer rates for maize and beans for the sole cropping and the rate recommended for maize for the intercropping was used. Maize and legume varieties selected by each center were used for the study.

Grain yield of maize and haricot bean under CA, CP, sole and intercropping at Melkasa is presented in Fig. 2. Intercropped (4.2 t ha^{-1}) and sole cropped (4.8 t ha^{-1}) maize showed higher grain yield under CP than under CA, which produced grain yield of 2.8 t ha^{-1} under intercropping and 3.2 t ha^{-1} under sole cropping. About a 50% grain yield reduction was observed under CA during this first year of CA practice, which was attributed to a lack of appropriate residue management and weed control. It is anticipated that CA will lead to a sustainable increase in crop productivity in the long term. Wider efforts on implementing CA-oriented practices in Africa showed the feasibility of CA-oriented systems under smallholder farm conditions (Wall *et al*., 2009). Common bean showed higher grain yield under CP (2.2 t ha^{-1}) than under CA (1.8 t ha^{-1}) while the same level of grain yield (0.6 t ha^{-1}) was observed for common bean intercropped with maize under both CP and CA.

Five best-bet treatments (including sole maize, sole haricot bean, 50% haricot bean population density intercropped with 100% maize population density, 100% haricot bean population density intercropped with 100% maize population density and farmers practice, where 30% of haricot bean population density intercropped in maize) were tested at Hawassa with the objective of selecting the best rate of intercropping and assessing the advantage of intercropping over sole cropping of maize and haricot bean. The results indicated that intercropping of maize with haricot bean had an advantage over sole planting of the component crops (Fig. 3). Farmers' practice showed higher maize grain yield and lower haricot bean yield followed by the treatment with 100% maize and 50% haricot bean population densities while intercropping of 100% maize and 100% haricot population densities yielded relatively lower maize grain and higher haricot bean seed.

At BARC, grain yield of maize was higher under CA than CP in sole cropping condition whereas maize grain yield was slightly lower under CA in maize–soybean intercropping condition (Fig. 4). Sole maize showed a yield advantage of 32% in CA as compared with the CP. In contrast, under maize–soybean intercropping the mean yield of maize in CA was 9.0% less than that of CP. There was a minimal decrease in grain yield of soybean in all cropping systems under CA as compared to CP. At PARC, maize grain yield was slightly higher under CA than CP, indicating the potential contribution of CA based faming systems to increase productivity of maize (Fig. 5) beginning from the early stage of the practice. In addition, CA practice provides long term merits in maintaining soil fertility and structure, soil and water management and weed control. On the contrary, grain yield of soybean was slightly higher in CP than that of CA under both sole and intercropping conditions. However, the study needs to be continued for some years to arrive at more conclusive results.

Land equivalent ratios (LERs) were calculated for maize–legume intercropped plots at all locations using the Mead and Wiley (1980) model to assess the grain yield advantage of intercropping as compared to sole cropping of the component crops. Accordingly, LERs of 1.2 and 1.2 were observed for maize–haricot bean intercropping under CP and CA, respectively at MARC. At HARC, the highest LER of 1.7 was obtained for intercropping of 100% haricot bean with 100% maize

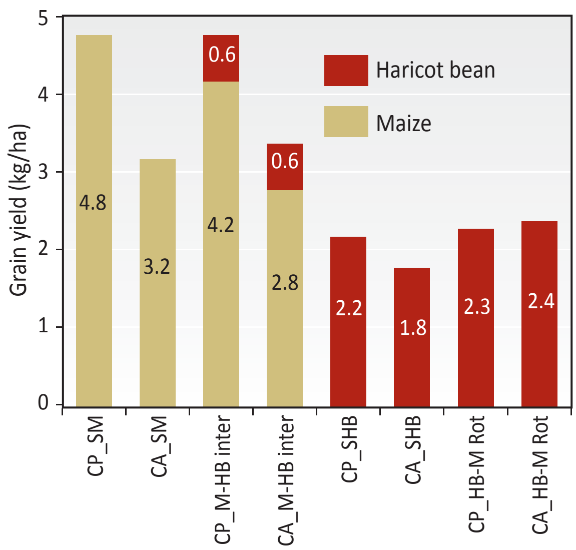

Figure 2. Grain yield (t ha^{-1}) of maize and haricot bean under conservation agriculture, conventional practice, sole and intercropping; and land equivalent ratio (LER) at Melkasa in 2010.

CP_SM = sole maize under conventional practice, CA_SM = sole maize under conservation agriculture, CP_M-HB = maize–haricot bean intercropping under conventional practice, CA_M-HB inter = maize–haricot bean intercropped under conservation agriculture, CP_SHB = sole haricot bean under conventional practice, CA_SHB = sole haricot bean under conservation agriculture, CP_HB-M Rot = haricot bean–maize rotation under conventional practice, CA_HB-M Rot = haricot bean–maize rotation under conservation agriculture.

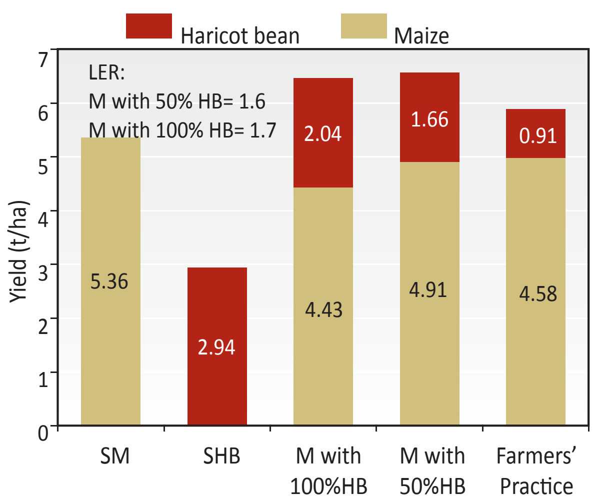

Figure 3. Grain yield of maize and haricot bean under sole and intercropping conditions; and land equivalent ratio (LER) at Hawassa in 2010.

SM = sole maize, SHB = sole haricot bean, M = maize, HB = haricot bean

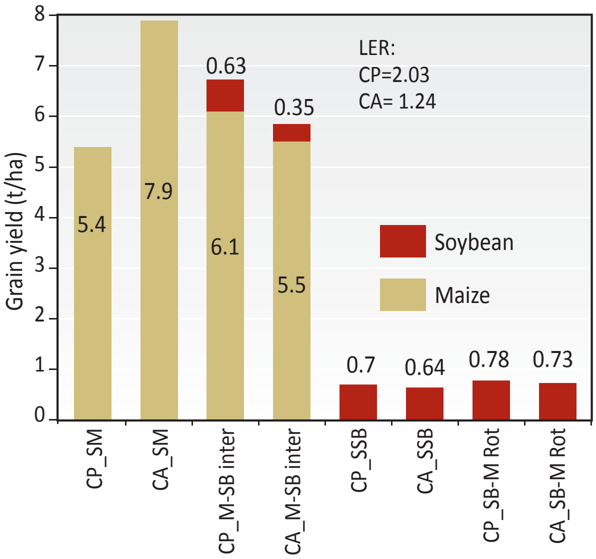

Figure 4. Grain yield (t ha^{-1}) of maize and soybean under conservation agriculture (CA), conventional practice (CP), sole and intercropping; and land equivalent ratio (LER) at Bako.

CP_SM = sole maize under conventional practice, CA_SM = sole maize under conservation agriculture, CP_M-SB = maize–soybean intercropping under conventional practice, CA_M-SB Inter = maize–soybean intercropped under conservation agriculture, CP_SSB = sole soybean under conventional practice, CA_SSB = sole soybean under conservation agriculture, CP_SB-M Rot = soybean–maize rotation under conventional practice and CA_SB-M Rot = haricot bean–maize rotation under conservation agriculture.

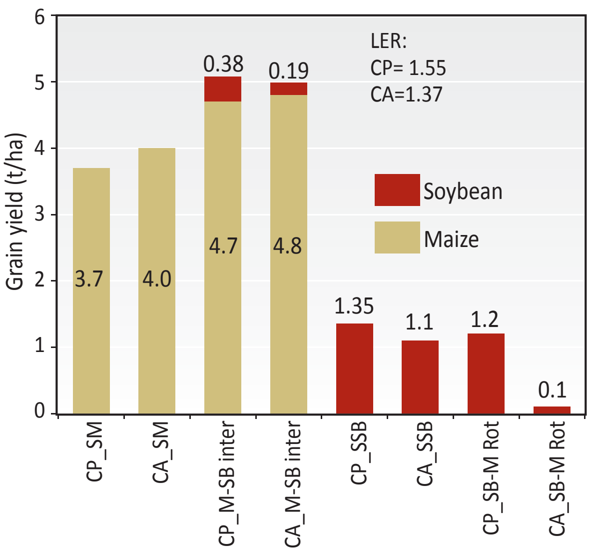

Figure 5. Grain yield (t ha^{-1}) of maize and soybean under conservation agriculture (CA), conventional practice (CP), sole and intercropping; and land equivalent ratio (LER) at Pawe.

CP_SM = sole maize under conventional practice, CA_SM = sole maize under conservation agriculture, CP_M-SB = maize–soybean intercropping under conventional practice; CA_M-SB Inter = maize–soybean intercropped under conservation agriculture, CP_SSB = sole soybean under conventional practice, CA_SSB = sole soybean under conservation agriculture, CP_SB-M Rot = soybean–maize rotation under conventional practice and CA_SB-M Rot = soybean–maize rotation under conservation agriculture.

while LER of 1.6 was realized for intercropping of 50% haricot bean with 100% maize. LER of 2.0 for CP and 1.2 for CA were obtained at Bako while LERs of 1.6 and 1.4 were observed in CP and CA, respectively at PARC. Since LERs greater than 1.0 show the greater advantage of intercropping, the LERs observed in the current study indicate that an intercropping system has potential in increasing total land productivity and efficient use of limited land resources.

On-farm exploratory trials

CA-based exploratory trials of integrated maize-legume cropping options with 3–5 treatments were established on 4–7 farmers' fields in each target community to compare CA options with CP under farmers' conditions. MARC conducted on-farm exploratory trials in five districts; *viz.* Boset, Dugda, Adami Tulu, Sire and Shalla. Each district had one research community; each research community consisted of five farmers. However, in one of the districts (Sire district) the trial was established only on three farmers' fields. Three treatments were used on each farmer-plot, these were:

1. Farmers' check: Traditional land preparation and maize crop management but with the same varieties, and fertilizer as the other treatments, and residues may be grazed, removed, burned or incorporated. In some areas farmers used inter-cropping while sole cropping was used in other areas.
2. Conservation agriculture (CA): No tillage, residue retained (mulch). Haricot bean intercropped between maize rows thirty days after maize planting.
3. Conservation agriculture with tie-ridging: No tillage, residue retained (mulch). Ridges tied at every 5 m between maize rows.

Maize variety Melkasa2 and haricot bean variety Nasir were used for the trial. Each plot consisted of 20 × 30 m plot area. Recommended fertilizer rates for maize and haricot bean were used for the sole cropping while the recommended rate for maize was used for the intercropping at all locations. Relevant agronomic, grain yield and yield components data were collected, but only grain yield data is presented in this paper. The overall results revealed that tie-ridging effectively conserved moisture and resulted in higher maize grain yield; especially, in moisture stressed areas e.g., Sire (Fig. 6). Intercropping was also found to be advantageous in providing a substantial amount of grain yield for both component crops, in addition to other advantages obtained from legumes in terms of soil fertility replenishment, nutritional quality, fodder, and cash source.

HARC identified three districts as target sites for the implementation of the exploratory trials. However, due to the late launching of the project only one district (Hawassa *Zuria*) was planted in 2010. In this district, one experiment containing five treatments was conducted on seven farmers' fields. The five treatments included sole maize (BH543), sole haricot bean (Hawassa Dumme), 100% maize and 100% haricot bean intercropping, 100% maize and 50% haricot bean intercropping and farmers' practice. Each treatment was planted on 10 m × 10 m plot size with 80 cm between rows and 25 cm between plants with two seeds per hill and 40 cm between row and 10 cm between plants for haricot bean. Recommended fertilizer rates and crop management practices were applied. Data collected for each trait were subjected to ANOVA using SAS computer software.

The results indicated that the highest maize grain yield was obtained from sole cropped maize followed by farmers' practice (Table 1). Grain yield of haricot bean was significantly higher for sole cropped plot (t ha^{-1}) whereas the lowest haricot bean grain yield was obtained with farmers' practice (0.8 t ha^{-1}), which was 250% less than the sole cropping (Table 1).

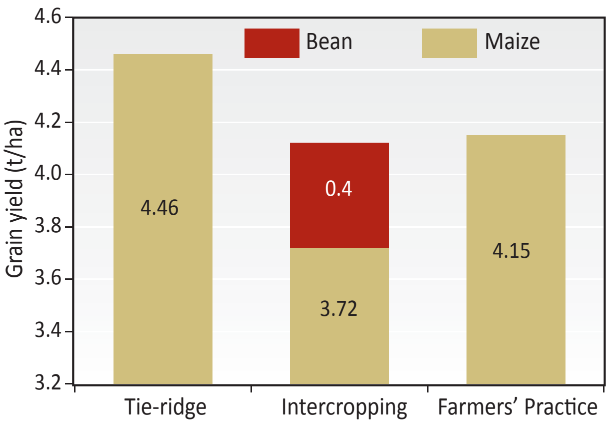

Figure 6. Maize and haricot bean grain yields (t ha^{-1}) under sole cropping and intercropping on farmers' fields in central rift valley of Ethiopia.

Table 1. Maize and haricot bean grain yields (t ha^{-1}) under sole cropping and intercropping on farmers' fields in Hawassa-*Zuria* district, Southern Ethiopia.

Cropping system†	Maize	Haricot bean
Sole maize	5.6	–
Sole haricot bean	–	2.8
Maize with 100% haricot bean	4.5	2.0
Maize with 50% haricot bean	5.1	1.5
Farmers' practice	5.2	0.8

† In intercropping, 100% recommended rates of maize were used.

BARC established two sets of exploratory trials each with four treatments. The first set (Set-I) consisted of CA-based sole maize and sole haricot bean, maize–haricot bean intercropping and haricot bean under CP planted on 10 m × 10 m plots on seven farmers' fields. The same approach was followed for the second set (Set-II) except that haricot bean was replaced by soybean. This trial was also conducted on seven farmers' fields. The results showed that grain yield of sole planted haricot bean variety (Anagr) was higher (1.6 t ha^{-1}) in CP than in CA (1.1 t ha^{-1}) while soybean variety (Dedessa) produced the same amount of grain yield (0.5 t ha^{-1}) under both CA and CP (Fig. 7). Both haricot bean and soybean gave a much lower grain yield when intercropped with maize than when under the sole cropping system. On average, maize produced higher grain yields under CP than when under CA-based intercropping; i.e., 4.8 t ha^{-1} under CP and 4.2 t ha^{-1} under CA-based intercropping in Set-I (Fig. 7), and 4.2 t ha^{-1} under CP and 3.7 t ha^{-1}under CA-based intercropping in Set-II (Fig. 8).

Participatory Maize Variety Selection

Participatory variety selection (PVS) efforts of the project used both existing and pre-released maize varieties in order to identify high yielding, stress tolerant and nutritionally enhanced maize varieties suitable for optimum and marginal environments. As part of the current program, those varieties that met the requirement of the agro-ecologies of the targeted farming systems and farmer preferences were evaluated under PVS to fast-track them for release and

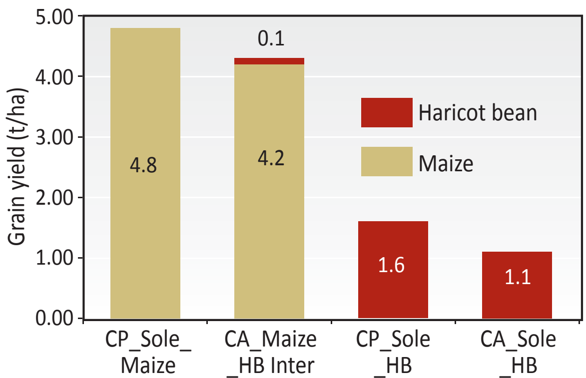

Figure 7. Maize and haricot bean grain yields (t ha^{-1}) under sole cropping and intercropping on farmers' fields in Gobu-Sayo and Bako-Tibe district, Western Ethiopia.

CP_Sole_Maize = sole maize under conventional practice, CA_Maize_HB Inter = maize haricot bean intercropping under conservation agriculture, CP_Sole_HB = sole haricot bean under conventional practice, CA_Sole_HB = sole haricot bean under conservation agriculture.

scaling up of seed production, and subsequently to be integrated and promoted as part of more productive, sustainable and risk-averting livelihood systems.

A number of PVS trials were carried out at different project target areas. The trials were co-located with the CA exploratory trials mentioned above. These PVS included a range of genetically different materials that suited each target area: low moisture stress tolerant, medium maturing and late maturing materials were included and tested at different locations in the year 2010. The results of each location are reported below.

MARC tested two sets of maize PVS trials in four districts (Boffa, Dugda, Adami Tulu, and Sire) each set on eight farmers' fields. The first set contained seven conventional maize (non-quality protein maize; QPM) varieties, and the second set contained five QPM varieties that were suitable for low moisture stressed conditions in selected districts. All management practices were carried out as per each area's

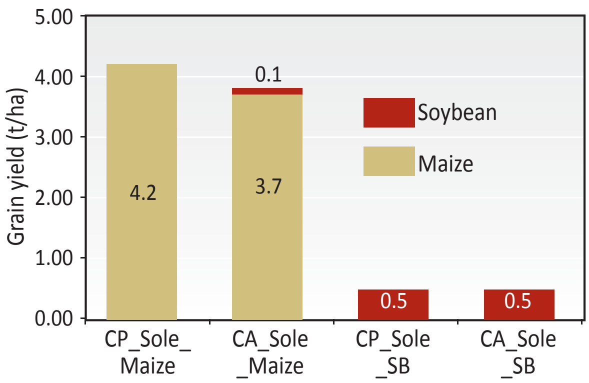

Figure 8: Maize and soybean grain yields (t ha^{-1}) under sole cropping and intercropping on farmers' fields in Gobu-Sayo and Bako-Tibe district, Western Ethiopia.

CP_Sole_Maize = sole maize under conventional practice, CA_Sole_Maize = sole maize under conservation agriculture, CP_Sole_SB = sole soybean under conventional practice, CA_Sole_SB = sole soybean under conservation agriculture.

recommendations. At dough stage of the crop, farmers' field days were organized and farmers were invited to select the best varieties that met their criteria of selection. First farmers were asked to set their own criteria used to categorize maize varieties as best or worse. The most important criteria they used to select the best variety were: earliness, number of ears per plant, ear size, ear placement, plant height, resistance to diseases and pests.

Based on their criteria of selection, recently released maize varieties Melkasa2 and Melkasa6Q were chosen from the normal and QPM sets, respectively. Across location field performance data collected by researchers indicated that the hybrid CML388SR/(CML202//CML395) followed by Melkasa2 produced higher grain yields of 4.9 and 3.8 t ha^{-1}, respectively among the non-QPM varieties (Table 2). In addition, Melkasa2 was earlier in maturity, indicating that farmers' selection was appropriate, especially for the drought prone area of the country like Melkasa area. For the QPM set, the hybrid, [MSRXPOOL9]C1F2-176-4-1-4-SnQPM/(CML144// CML159) followed by another hybrid, CML387Q/(CML144//CML159) produced higher grain yields of 5.3 and 5.0 t ha^{-1}, respectively (Table 3). However, these hybrids were later in maturity than Melkasa6Q; hence, were not selected by farmers.

The PVS trial was also carried out by HARC. Five genotypes, two hybrids (BH540 and BH543) and three OPVs (Gibe1, Gibe2 and Gibe3), were evaluated on three farmers' fields and on-station. These materials were planted on 10 × 10 m plot size with 75 cm and 30 cm inter- and intra-row spacing, respectively. Fertilizer was applied as per the recommendation given for area (46 kg N and 46 kg P_2O_5). These PVS trials were visited by farmers, district agriculture office experts, development agents in the villages and researchers. The varieties were subjected to farmers' selection at dough stage of the crop and at harvest. Before

Table 2. Performances of conventional maize varieties evaluated under participatory variety selection across locations on farmers' fields in central rift valley of Ethiopia, 2010.

Pedigree/Name	Grain yield (t ha^{-1})	Days to anthesis	Days to silking	Plant height (cm)	Farmers' perception (rank)
CML206/CML312]-B-1-2-1-1-1-2//CML202/CML395	2.2	74.5	77.5	195.0	4
CML388SR/(CML202/CML395)	4.9	72.5	74.0	212.5	3
Melkasa2	3.8	67.5	68.5	207.5	1
Melkasa3	3.1	67.0	68.0	172.5	7
Melkasa4	3.0	65.5	66.5	200.0	6
Melkasa5	3.6	68.0	69.5	200.0	2
Melkasa7	3.1	62.0	63.0	182.5	5
Mean	3.4	68.1	69.6	195.7	
$LSD_{0.05}$	0.5	1.3	3.4	15.6	

LSD = least significant difference.

beginning the selection process, farmers were asked to set their priority selection criteria. Accordingly, yield potential, disease/pest resistance, cob size, ear rot and husk cover were identified as the most important farmers' selection criteria.

The results of analysis of data recorded by researchers indicated that there were significant differences among genotypes for ear and plant height, grey leaf spot (GLS) and *phaespheria* leaf spot (PLS) diseases and grain yield. The OPV Gibe2 and the hybrid BH543 had higher grain yield and also showed a resistant reaction to GLS. The highest grain yield was obtained for the recently released hybrid BH543 (7.6 t ha^{-1}) followed by the candidate OPV Gibe2 (5.7 t ha^{-1}) (Table 4). OPV Gibe2 gave 23.9% grain yield advantage over the OPV check Gibe1. Gibe2 was a candidate variety presented by National Maize Research Project to the National Variety Release Committee for possible release in the same season. Accordingly, the committee evaluated and verified the performance of the variety and recommended it for official release for commercial production.

Seed road-maps were developed to accelerate the production of different seed classes of the selected varieties to accelerate the process of seed supply to small scale farmers. The PVS approach contributed to increased ranges of maize varieties available for smallholders through accelerated breeding and release. In the future, promising varieties developed by donor supported and national projects that meet the requirement of the climatic and edaphic conditions of the targeted farming systems and farmer preferences should be fast-tracked for release through PVS and scaled-up seed production, and subsequently integrated and promoted as part of CA-based cropping system.

Two trials (one OPV and one hybrid) were planted on farmers' fields to assess the performance of promising varieties with farmers' participation by Bako National Maize Research Project around Bako. The hybrid trial consisted of four late maturing hybrid varieties (2 candidate and 2 checks) while the OPV trial consisted of three OPVs (1 candidate and 2 released) (Table 5). The results showed that BH661, proposed for release, out yielded all the three varieties included in the hybrid trial. Likewise, farmers selected the same variety by their own criteria. In the OPV trial, the candidate varieties were better than the best OPV used as standard check, Gibe1. Gibe2, the topmost yielding OPV of all three, showed more than 12% grain yield advantage over Gibe1 while Gibe3 was only 3% better than the standard check. Similar to field performance, Gibe2 was also ranked first for all farmers' evaluation criteria. Generally, considering

Table 3. Performances of quality protein maize (QPM) varieties evaluated under participatory variety selection across locations on farmers' fields in central rift valley of Ethiopia, 2010.

Pedigree/Name	Grain yield (t ha^{-1})	Days to anthesis	Days to silking	Lodging (%)	Farmers' perception (rank)
CML387Q/CML144//CML159	5.0	57.0	57.5	3.2	5
CML202Q /CML144//CML159	4.9	55.0	56.0	5.2	3
[MSRXPOOL9]C1F2-176-4-1-4-SnQPM /CML144//CML159	5.3	56.5	58.5	3.0	2
CML202Q/Obatampa	4.7	51.0	51.5	3.8	4
Melkasa6Q	3.8	50.0	51.5	3.0	1
Mean	4.7	53.9	55.0	3.7	
$LSD_{0.05}$	0.7	0.9	1.8	0.3	

LSD = least significant difference.

Table 4. Performances of maize varieties (hybrids and open-pollinated varieties; OPVs) evaluated under participatory variety selection across locations on farmers' fields in Dore Bafano district of Southern Ethiopia, 2010.

Entry	Plant height (cm)	Ear height (cm)	Gray leaf spot (Scale 1–5)	*phaespheria* leaf spot (Scale 1–5)	Grain yield (t ha^{-1})	Farmers' perception (rank)
Gibe2	196.8	105.8	1.6	2.3	5.7	2
Gibe3	210.8	111.5	1.8	1.9	5.1	4
Gibe1	213.0	118.8	3.0	1.6	4.6	5
BH540	227.3	115.5	2.0	1.6	5.3	3
BH543	233.0	125.8	1.6	1.4	7.6	1
Mean	216.2	115.5	2.0	1.8	5.6	
$LSD_{0.05}$	26.50	9.04	0.8	0.5	1.8	

LSD = least significant difference.

Table 5. On-farm participatory evaluation of maize varieties for grain yield and other traits at Bako.

Entry	Pedigree	Yield (t ha^{-1})	Ear rot (%)	Ears/ plant ratio	Ear aspect (1–5)	Yield advantage (%)	
		Hybrid trial				BH660	BH670
1	BH661	6.6	4.0	1.1	2.3	17	23
2	BH662	6.0	4.6	1.0	2.4	6	12
3	BH660	5.7	3.5	1.1	2.3		
4	BH670	5.4	5.3	1.0	2.5		
		Open-pollinated variety trial				Gibe1	
1	Gibe2	5.8	6.6	1.0	2.1	12.7	
2	Gibe3	5.3	6.6	1.0	2.8	3.1	
3	Gibe1	5.1	5.9	0.9	2.8		

both field performance and farmers' assessment, BH661 among hybrids and Gibe2 among OPVs were found to be the best varieties. The same varieties also showed good performance across locations in verification trials planted across locations. As a result, these varieties were officially released for commercial production in the mid-altitude sub-humid agro-ecology of Ethiopia.

Future Direction

- The results of CA and PVS trials presented in this paper were from a one year trial and need to be repeated over years to come up with conclusive results and identify more dependable best-bet integration options.
- Selection of maize varieties for intercropping compatibility and CA system through farmers' PVS.
- Introduce time, energy and labor saving CA implements along with conservation agriculture-based cropping systems.
- Conservation agriculture may not be effective without a sufficient quantity of residue retention. On the other hand, maize stalks after harvest are used as fodder, fuel and construction material. Therefore, identifying alternative feed and firewood sources will enhance the process of CA adoption.
- Establish strong local innovation systems through which groups of farmers exchange experiences and share knowledge amongst themselves and with researchers, extension agents, traders and agro-input suppliers.
- Organize field days and exchange visits regularly; and use mass media for fast technology dissemination and adoption.
- Establish strong collaboration with public and private seed producers so as to improve seed delivery systems to accelerate the adoption and impact of improved varieties.

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Soil Fertility Management Technologies for Sustainable Maize Production in Ethiopia

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Introduction

The fundamental biophysical cause of stagnant per capita food production in Africa is soil fertility depletion (Sanchez, 2002). The author emphasizes that soil fertility depletion must be addressed before other technologies and policies can become effective in overcoming hunger and poverty in countries like Ethiopia. Inappropriate land use systems, mono-cropping, nutrient mining, expansions of agriculture to marginal lands and inadequate supply of nutrients have aggravated the soil fertility depletion in the country. Using high yielding maize varieties have also accelerated nutrient depletions in the major maize producing regions like western Oromia zones. Furthermore, returning little organic materials into soils results in low soil organic matter (SOM), poor soil structure, high bulk density, poor available water holding capacity and susceptibility to accelerated erosion and runoff which either directly or indirectly contribute to low crop yield (Wakene and Heluf, 2003a, b). Applications of chemical fertilizers on soils with low SOM discourage smallholder farmers to use costly chemical fertilizers because of low return of fertilizer investment. Thus, not only plant nutrients, but also SOM depletion is severe in Ethiopian soils where crop residues and manures are a source of cash and energy (Sanchez *et al.,* 1997). Therefore, the objectives of this review are to (i) compile soil fertility management technologies generated for maize based farming systems in the past ten years, and (ii) propose future research and development interventions for soil fertility management in the country.

Soil Fertility Management Technologies

Recommended rate of NP fertilizers

The optimum NP fertilizer rates for maize production in different parts of the country are summarized in Table 1. A study conducted on NP fertilizer rates for BH660 and Gibe1 indicated that N significantly increased grain yield, whereas P had little contribution (Tolessa *et al.,* 2007). On the other hand, application of the highest NP fertilizers (180/61 kg N/P ha^{-1}) increased maize grain yield at Achefer with a grain yield advantage of 3.7–7.2 t ha^{-1} over the control (0/0 kg N/P ha^{-1}) (Tilahun *et al.,* 2007a). These can be explained by genetic potential differences among the varieties and locations in nutrient use efficiency and soil fertility status, respectively. Furthermore, nitrogen fertilizer use efficiency of maize depended on seasonal distribution of rainfall. For instance, 90 and 27% of the total variation in maize yield was due to difference in precipitation in 1994 and 1995 cropping seasons, respectively, in southern Ethiopia. Accordingly, the mean maize grain yields with N fertilizer application were 7.7 and 4.7 t ha^{-1} with favorable and unfavorable rainfall distributions, respectively. Furthermore, nitrogen fertilizer application under erratic rainfall distribution reduced grain yield by 4.8% as compared to the treatment without soil amendment (unpublished data). This clearly showed that increasing the rate of N fertilizer application can increase maize grain yield only if there is adequate rainfall distribution. The highest recommended rate of P fertilizer in the form of di-ammonium phosphate was in the range of 20–30 kg P ha^{-1} for the major maize producing regions and/or locations except at Achefer (61 kg P ha^{-1}) and Pawe (0 kg P ha^{-1}). The lack of response to P application at Pawe needs further investigation since P is expected to limit maize production in agro-ecosystems. Although many NP fertilizer rate studies have been conducted across the country, there is no information on fertilizer and maize variety interactions except the recent work of Tolessa *et al.* (2007).

Time and methods of NP fertilizer application

The recommended rate of P fertilizer was applied in the form of di-ammonium phosphate at maize planting, whereas N fertilizer was applied in the form of urea in two to three splits depending on the agro-ecology. For instance, the recommended N fertilizer rate was applied in three splits; one-third at planting, one-third at knee height and one-third at tasseling (flowering) for highland maize, whereas, in two splits; half at planting and half at knee height for maize growing in mid-altitude sub-humid agro-ecologies. However, the full dose of recommended N fertilizer was applied at knee height for moisture stress areas. Tilahun *et al.* (2007b) observed yield variations between maize varieties due to time of N fertilizer applications. Accordingly, the authors recommended applying one-third and two-thirds of the recommended N fertilizer at planting and knee height for BH540, whereas one-fourth and three-fourths at planting and knee height for BH660, respectively. The P and N fertilizers were applied at spot about 3–5 cm away from the seed at planting, whereas N fertilizers were either side or top dressed at knee height and/or tasseling. Nowadays, it is nice to notice that the time and methods of NP fertilizer applications along with other cultural practices have been well adopted by most of the smallholder farmers producing maize in Ethiopia.

Integrated use of cropping systems and fertilizers

Niger seed (*Guizotia abssnica* L.) and haricot bean (*Phasoles vulgares* L.) were found to be the best precursor crops for maize production with or without the application of the recommended rate of NP fertilizers, at Bako, western Ethiopia (Table 2). The N, P and K concentrations in grain and leaves were also higher in maize grown after niger seed and haricot bean than that of monocropping and after *tef* (*Eragrostis tef* L.) (Tolera *et al.,* 2009). This showed that using legumes and oilseed crop rotations in maize based farming systems can increase maize grain yield and nutrient uptake. Accordingly, maize following niger seed and haricot bean with 110/20 kg N/P ha^{-1} was recommended for maize production in the Bako area.

Table 1. Optimum NP fertilizer rates recommended for maize production in Ethiopia.

N (kg ha^{-1})	P (kg ha^{-1})	Locations	Source
60	20	Basoliben, Mecha and Yilmana	Tilahun *et al.,* 2007a
60	20	Denssa and Ankesha	Tilahun *et al.,* 2007a
60	20	Jabi Tenan	Tilahun *et al.,* 2007a
120	20	Burie and Huleteju Enebsie	Tilahun *et al.,* 2007a
180	61	Achefer	Tilahun *et al.,* 2007a
119	30	Adet	Unpublished data
87	20	Haramaya	Unpublished data
110	20	Ambo	Unpublished data
119	30	Holetta	Unpublished data
110	20	Hawassa	Unpublished data
119	30	Jimma	Unpublished data
119	30	Bako	Unpublished data
96	30	Gimbi	Unpublished data
41	20	Gambela	Unpublished data
41	20	Melkasa	Unpublished data
69	0	Pawe	Assefa *et al.,* 2009

Although Ethiopian farmers know that legume and oilseed crop rotations improve soil fertility and increase crop yields, the mystery of niger seed in improving soil fertility is not well understood. Although some people speculate that the defoliation of niger seed at maturity could contribute to improved soil fertility, the recent study showed that niger seed cake had also the highest concentration of N and P, 4.8 and 1.2 %, respectively, as compared with the traditional organic fertilizers like farm yard manure (FYM), compost and green manure (Wakene *et al.,* 2010, 2011). Therefore, understanding the mechanism of niger seed in improving soil fertility needs in-depth research.

The integrated use of niger seed precursor with NP fertilizers and FYM (46/5 kg N/P and 8 t FYM ha^{-1}) was recommended for maize production in the Bako areas, western Ethiopia (Tolera *et al.,* 2005a) (Table 2). Similarly, maize planted following sole haricot bean gave higher maize grain yield than that of maize following maize-haricot bean intercropping (Table 2). However, the intercropping was more productive in terms of yield per unit area and combined yields of maize and haricot bean than sole cropping as revealed by the higher land equivalent ratio (LER) than sole cropping (Tolera *et al.,* 2005b). Accordingly, the combined application of 78/10 kg N/P ha^{-1} and 4 to 8 t FYM ha^{-1} were recommended for maize-climbing bean intercropping.

Integrated use of inorganic and organic fertilizers

The combined application of 8 tons biogas slurry with 55/10 kg N/P or 12 tons biogas slurry ha^{-1} alone was recommended for maize production (Tolera *et al.,* 2005c). Installing a biogas plant helped to generate energy for cooking and heating that can alleviate deforestation, and release organic materials like crop residues for animal feed and biogas slurry for soil amendment. Therefore, supporting the current government's and non-governmental organizations' efforts in expanding biogas plants across the country could help to generate energy and maintain soil fertility at the same time. However, more research and development endeavors are required to investigate the potential of industrial byproducts and urban waste for biogas plant and soil amendment which could be one of the safest waste disposal mechanisms to alleviate their contribution to environmental pollution.

The integrated use of coffee byproducts and N fertilizer increased N uptake by 213%, whereas the sole application of N fertilizer increased N uptake by 149% over the control treatment at Hawassa, southern Ethiopia (Tenaw, 2006). Furthermore, the integrated use of coffee byproducts and N fertilizers increased both haricot bean and maize grain yield by 91% over the control. The recent study also revealed that wet processed coffee byproducts (pulp) were superior to dry processed coffee byproducts (husk) in most of the essential elements in general and N concentration in particular (Wakene *et al.,* 2010, 2011). These authors also showed that both coffee byproducts contained extraordinary concentrations of K that can be used for replenishing K deficient soils.

The integrated use of five tons of compost with low doses of NP fertilizers (55/10 or 25/11 kg N/P ha^{-1}) appeared to be economical for maize production (Wakene *et al.,* 2004). Furthermore, the integrated use of improved fallow of *Mucuna pruriens* L. with low doses of FYM and NP fertilizers improved maize grain yield, selected soil properties and nutrient uptake by maize (Wakene *et al.,* 2007). The three year average maize grain yield showed that using improved fallow alone doubled the maize grain yield as compared with treatment without any amendment. However, crops to be used as improved fallow should have economic values in addition to replenishing soil fertility so that farmers will easily adopt. In general, advising farmers in using locally available decomposable materials and multipurpose legumes along with low doses of NP fertilizers can be used for sustaining maize production and productivity in Ethiopia.

Land use effects on soil health

Although there are no designed long-term experimental fields under Ethiopian conditions, the study super imposed on long-term cultivated farmers and research fields revealed that soil bulk density, soil pH, exchangeable bases, cation exchange capacity and organic carbon and associated nutrients were deteriorated both under low and high input agricultural practices (Dawit and Lehmann, 2000; Dawit *et al.,* 2002a, 2002b, 2002c, 2003; Wakene and Heluf, 2003a, 2003b, Heluf and Wakene, 2006). For instance, forest clearing and continuous cultivation depleted up to 63% of soil organic carbon (SOC) under smallholder farmers in southern Ethiopia (Dawit *et al.,* 2002a), whereas the depletion was extended up to 79% under mechanized cultivation in western Ethiopia within three decades (Wakene and Heluf, 2003a). Furthermore, the continuous application of more than 75 kg N ha^{-1} for seven years highly decreased soil pH and increased exchangeable acidity at Bako (Wakene *et al.,* 2005 unpublished). Since the only applied essential elements are N and P in the form of urea and diammonium phosphate (DAP) under Ethiopian conditions, the Zn, B, and Mo were found to be deficient while Mn and Fe are in the toxicity level in acid soils of western Ethiopia (Wakene and Heluf, 2003a). Although most of the micronutrients are expected to be deficient in most of the semi-arid and arid environments, there is

Table 2. Integrated use of precursor crops, N/P fertilizers and farm yard manure (FYM) on maize grain yield on Bako Nitisols.

Precursor crop	N/P/FYM†	t ha^{-1}	Location	Reference
Maize-bushy haricot bean	110/20/0	6.4	Bako	Bako Agricultural Research Center, 2007
Maize-climbing haricot bean	110/20/0	7.8	Bako	Bako Agricultural Research Center, 2007
Bushy haricot bean	110/20/0	6.7	Bako	Bako Agricultural Research Center, 2007
Climbing haricot bean	110/20/0	8.1	Bako	Bako Agricultural Research Center, 2007
Maize	110/20/0	6.7	Bako	Bako Agricultural Research Center, 2007
Mucuna pruriens	0/0/0	4.7	Bako	Wakene *et al.,* 2007
Mucuna pruriens	55/10/0	5.9	Bako	Wakene *et al.,* 2007
Mucuna pruriens	37/7/0	5.8	Bako	Wakene *et al.,* 2007
Mucuna pruriens	0/0/4	6.3	Bako	Wakene *et al.,* 2007
Maize	110/20/0	4.4	Bako	Wakene *et al.,* 2007
Mucuna pruriens	0/0/ 0	5.1	Bako	Tolera *et al.,* 2005a
Mucuna pruriens	46/5/8	7.5	Bako	Tolera *et al.,* 2005a
Maize	110/20/0	8.6	Bako	Tolera *et al.,* 2005a
Niger seed	110/20	7.2	Bako	Tolera *et al.,* 2009
Haricot bean	110/20	6.3	Bako	Tolera *et al.,* 2009
Tef	110/20	5.7	Bako	Tolera *et al.,* 2009
Maize	110/20	4.5	Bako	Tolera *et al.,* 2009
Niger seed	0/0/ 0	5.9	Bako	Tolera *et al.,* 2009
Niger seed	46/5/8	9.0	Bako	Tolera *et al.,* 2009

† N/P = kg ha^{-1}; FYM = t ha^{-1}

limited information, even though these environments cover large areas of Ethiopia. These results showed that both low input traditional and intensive mechanized agricultural practices can deteriorate soil quality parameters unless appropriate soil management practices are employed.

Research Gaps

The single-disciplinary research approaches in generating and dissemination of agricultural technologies in general and that of soil fertility management in particular have had short-term impacts in Ethiopia because a single technology cannot solve the complex problems of smallholder farmers. For instance, farmers need cash for different purposes, energy for cooking, high yielding food and feed crops, improved breeds of livestock, multipurpose trees, fertile soils, enough water etc. If one of these important elements is missed, the adoption and/or impact of any technology cannot improve the livelihoods of smallholder farmers. The Sasakawa Global 2000 (SG2000) and regular extension systems of the 1990s in Ethiopia can be cited as a good example where agricultural technology popularization totally depended on improved crop varieties, NP fertilizers and herbicides with little emphasis on important farming components such as cropping systems, soil and water management and income generating capacity of the technologies. In general, agricultural technology generation and dissemination neglected fundamental problems that hinder the achievement of sustainable development. This is because commodity approaches can not completely solve the complex socio-economic problems of smallholder farmers. It has been clearly showed that improving the whole farming system can alleviate the complex problems of smallholder farmers for sustainable crop production and natural resources management in Ethiopia.

Future Research Directions

Either the integrated or sole use of inorganic and organic fertilizers were found to be promising in improving maize yield and soil fertility along with appropriate farming systems. However, most of the organic materials such as crop residues and FYM can be used as sources of energy and income instead of being used for soil amendment. Therefore, looking for alternative sources of energy and income could help to release organic materials for soil amendment. Furthermore, evaluating diverse multipurpose trees under smallholder farmers can release FYM and crop residues for soil fertility improvement by providing alternative sources of energy and construction materials. Although N and P are the most limiting elements in Ethiopian soils, research is urgently required on other macro- and micronutrients particularly in the "high potential" agro-ecologies where native plant nutrients have been mined for centuries with little external inputs. Furthermore, developing fertilizer equivalent values of organic materials, and characterizing and evaluating industrial and urban wastes for soil amendment can help to safely recycle into agricultural soils so that their contribution to environmental pollutions may be alleviated. Future research should also focus on specific NP fertilizers recommended for specific soil types and maize varieties across the country. Special consideration should be given in developing maize varieties tolerant and/or resistant to soil acidity, salinity, and low nutrients environments.

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Weed Management Research on Maize in Ethiopia: A Review

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Introduction

Maize is an important crop because of its high productivity per unit area, suitability to major agro-ecologies and compatibility with many cropping systems (Tesfa *et al.,* 2002). Weeds are among the principal constraints to maize production in Ethiopia. The damage caused by weeds is multidimensional; they reduce crop yield and the quality of produce by depleting the crop's environment of nutrients, water and light. In addition, weeds interfere and cause inconvenience to agricultural operations (Rezene, 1991).

Competition of maize with annual and perennial grass and broadleaf weeds is still responsible for the grain yield reduction in maize (Kasa *et al*., 2002). The extent of losses due to weeds depends on the intensity of infestation, time of occurrence, and types of weeds. Earlier weed loss assessment estimates show that grain yield reduction due to weed interference in maize can be as high as 58.1% (Rezene, 1985). Although recommendations have been issued for the herbicidal control of broadleaf and grass weed species, adoption of herbicide-based technologies by small holders are often slow because cash and/or credit limitations hinder their procurement of the relatively expensive imported chemical products (Rezene *et al*., 1990; Nigussie *et al*., 1996; Mohammed *et al*., 1996; Amanuel *et al*., 1992). Hence, the complementarities between different manual and herbicidal methods of weed control justify the need for the identification and selection of appropriate weed management methods to control aggressive weed species, which obstruct productivity of maize (Kasa *et. al*., 2002). Therefore, the objectives of this paper are to review research results of the past decade, to indicate research gaps, and suggest future direction.

Research Achievements

The maize growing belts are infested by hard to control sedge and grassy weeds while the lowlands are invaded by alien invasive species such as *Parthenium hystrophorus*, *Prosopis juliflora* and *Lantana camara* (Rezene, 1985). However, few research attempts have been made to minimize the problems associated with weeds in maize in the last decade. The results of different weed control options are discussed below.

Manual weeding

At Hawassa, the critical period of weed competition in maize was between 31 and 49 days after emergence (DAE) (Mengistu *et al*., 2005). The authors recommended two weedings at the start and end of the period in order to reduce the competitive effect of weeds significantly. However, keeping maize weed-free throughout the cropping season is preferred to attain the highest possible yield.

The cost of weeding increased and grain yield declined as the time of weed removal was delayed. Yield loss due to the presence of weeds during the first 6, 9 and 12 weeks after emergence, and for the entire growing season were 36, 61, 80 and 85%, respectively (Assefa, 1999). However, it was found that early weeding at 20–25 DAE could be sufficient to increase grain yield when compared to the control at two locations: Melkasa and Wolenchi. Low input agriculture is a common feature of food production in Ethiopia. Because of the limited resource base, the subsistence farming community relies on hand weeding for the control of weeds. Because of the overlap of farm operations; however, farmers either leave their farms un-weeded or perform weeding late in the season.

Chemical control

An experiment conducted at Abobo Research Center, in the Gambela Region, to look at growth and yield response of maize to tillage practices and to compare a pre-emergence herbicide with different hand weeding regimes revealed that Gesparim combi herbicide at a rate of 3.5 kg a.i ha^{-1} kept the crop weed-free throughout the season. Furthermore, it was less costly. This herbicide was considered particularly appropriate for the Gambela Region where labor is in short supply (Wondimu *et al*., 2001). Chemicals are one of the most important weed control methods in modern maize production. The complementarities of hand manual weeding and chemical control justify the need for selection of promising herbicides.

Integrated weed management practices in the Ethiopian Highlands

It was reported that different weed management practices significantly (P<0.01) adversely affected grain yield and some other morpho-agronomic traits of maize at Holetta. The pre-emergence herbicide Lasso+Atrazine supplemented with one hand weeding at 50–55 d after crop emergence gave the highest grain yield of maize (5,593 kg ha^{-1}). Lasso+Atrazine weed treatment supplemented with one hand weeding (hoeing and hand pulling) at 30–35 days after emergence also showed relatively similar results while lowest grain yield (3,393 kg ha^{-1}) was obtained in the control treatment. Moreover, the weedy check treatment resulted in lowest number of ear per plant, poor plant and ear aspects (Table 1). Some maize growth parameters were also significantly affected by weed management treatments. From the study it was shown that even though distribution and infestation of weed species is affected by environmental factors, to protect early stage crop damage by fast growing weed species, it is pertinent to use Lasso+Atrazine pre-emergence herbicide supplemented with once hand weeding.

As an approach for integrated weed management, a study was conducted to evaluate the effect of maize population density on weed species distribution and infestation as well as to maximize maize grain yield potential gain. Accordingly intra-row spacing significantly (P<0.01) affected some of the agronomic yield and yield related traits of maize. The highest grain yield of maize was obtained from the highest population density (66,666 plants ha^{-1}) while the lowest grain yield (3,928 kg ha^{-1}) was obtained on the lowest plant density (38,095 plants ha^{-1}) which is 35 cm intra-row spacing (Table 1). The narrowest intra-row spacing resulted in an increased plant height, reduced days to anthesis and silking (Table 1). Also, a lower proportion of shoot lodging was observed at wider intra-row spacing (data not shown). On the other hand, there was no significant interaction effect of different weed management practices by intra-row spacing for all the agronomic parameters except plant height and ear aspect.

On the other hand, different weed management practices significantly affected weed species distribution. The highest value of individual weed score (1–5 scale) was recorded in the weedy check treatment (Tables 2 and 3). Accordingly, *Setaria pumila*, *Caylusia abyssinica,* and *Corrigola capensis* were found to be among the most abundant weed species affecting maize grain yield during 2005 cropping season. Likewise, *Snowdenia polystachi*, *Polygonum nepalense*, *Galium spurium* and *Galinsoga parviflora* were found to be abundant weed species in the control treatment (weedy check). Likewise, general weed control score (1–5 scale: low–high) was high for check treatment followed by W_4 (twice hand weeding). The highest weed biomass (kg) was also recorded in the check treatment followed by W_3 (herbicide treatment alone)

Table 1. Effect of weed management practices and intra-row spacing on yield and some yield components of highland maize at Holetta combined over two years (2005 and 2006).

Weed mgt practice	Ear per plant	Ear aspect (1–5)	Plant aspect (1–5)	Grain yield (kg ha^{-1})	Days to anthesis	Days to silking	Plant height (cm)
W_1	1.0 ab†	2.5 b	2.4 b	5,264 ab	104.5 ab	106.5 ab	235.9 a
W_2	1.1 a	2.6 b	2.5 b	5,593 a	103.5 bc	105.5 bc	232.2 ab
W_3	1.0 b	2.4 b	2.6 b	4,913 b	103.3 bc	105.5 bc	231.6 ab
W_4	1.0 ab	2.6 b	2.5 b	4,961 b	102.6 c	104.8 c	228.2 ab
W_5	0.8 c	3.2 a	3.0 a	3,393 c	105.3 a	107.2 a	224.5 b
MEAN	1.0	2.7	2.6	4,826	103.9	105.9	230.5
CV (%)	18.4	16.7	28.2	16.0	2.2	2.0	5.4
Intra-row spacing							
S_1	0.9 a	2.6 a	2.9 a	5,561 a	102.5 b	104.7 b	231.9 ab
S_2	1.0 a	2.6 a	2.5 a	5,067 b	103.7 a	105.9 a	235.1 a
S_3	1.0 a	2.7 a	2.5 a	4, 694 b	104.3 a	106.3 a	229.4 ab
S_4	1.0 a	2.8 a	2.5 a	3,928 c	104.8 a	106.5 a	225.4 b
MEAN	0.97	2.7	2.6	4,826	103.9	105.9	230.5
CV (%)	18.40	16.7	28.2	16.0	2.2	2.0	5.4

† Values followed by the same letters within a column are not significantly different from each other. W_1 = Pre-emergence herbicide + once hand weeding at 30–35 DAE, W_2 = Pre-emergence herbicide + once hand weeding at 50–55 DAE, W_3 = Pre-emergence herbicide only, W_4 = Twice hand weeding at 30–35 and 50–55 DAE, $W_{5=}$ Weedy check, DAE = Days after emergence, S_1 = 20 cm intra-row spacing (66,666 plants ha^{-1}), S_2 = 25 cm intra-row spacing (53,333 plants ha^{-1}), S_3 = 30 cm intra-row spacing (44,444 plants ha^{-1}), and S_4 = 35 cm intra-row spacing (38,095 plants ha^{-1}), CV = coefficient of variance.

Table 2. Effect of weed management practices and intra-row spacing on weed species distribution at Holetta, 2005 cropping season.

Weed mgt practice	Individual weed score (1–5)					
	Caylusia abysinica	*Polygonum nepalense*	*Erucastrum arabicum*	*Setaria pumila*	*Corrigola capensis*	*Oxygonum sinuatum*
W_1	1.1 b†	1.1 b	1.0 b	1.2 b	1.2 b	1.2
W_2	1.1 b	1.1 b	1.0 b	1.0 b	1.0 b	1.1
W_3	1.1 b	1.0 b	1.0 b	1.0 b	1.0 b	1.0
W_4	2.6 a	1.6 a	1.2 ab	3.0 a	2.5 a	1.3
W_5	2.6 a	1.5 a	1.3 a	3.1 a	2.5 a	1.3
EMS	0.2	0.1	0.1	0.6	0.2	0.1
P	<0.01	<0.01	<0.01	<0.01	<0.01	NS
MEAN	1.7	1.3	1.1	1.9	1.6	1.2
CV (%)	25.6	28.9	22.2	40.2	25.0	26.9
Intra-row spacing						
S_1	1.7 a	1.2 a	1.1 b	1.9 a	1.5 a	1.1 a
S_2	1.7 a	1.3 a	1.0 b	1.9 a	1.6 a	1.2 a
S_3	1.8 a	1.3 a	1.3 a	2.0 a	1.6 a	1.3 a
S_4	1.6 a	1.2 a	1.1 b	1.6 a	1.8 a	1.1 a
MEAN	1.7	1.3	1.1	1.9	1.6	1.2
CV (%)	25.6	28.9	22.2	40.2	25.0	26.9

† Values followed by the same letters within a column are not significantly different from each other.
W_1 = Pre-emergence herbicide + once hand weeding at 30–35 DAE, W_2 = Pre-emergence herbicide + once hand weeding at 50–55 DAE, W_3 = Pre-emergence herbicide only, W_4 = Twice hand weeding at 30–35 and 50–55 DAE, $W_{5=}$ Weedy check, DAE = Days after emergence, S_1 = 20 cm intra-row spacing (66,666 plants ha^{-1}), S_2 = 25 cm intra-row spacing (53,333 plants ha^{-1}), S_3 = 30 cm intra-row spacing (44,444 plants ha^{-1}), and S_4 = 35 cm intra-row spacing (38,095 plants ha^{-1}), CV = coefficient of variance.

Table 3. Weed species composition on maize in West Shewa during 2005 and 2006 cropping season.

Weed species composition	Weed species (m^2)					
	Meti		Toke		Mutulu	
	IWM	Farm	IWM	Farm	IWM	Farm
Bidens pachyloma	1	4	1	45	0	0
Galinsoga parviflora	68	149	20	73	82	161
Cardus chamacephalus	0	0	1	5	0	0
Snowdenia polystachya	7	46	22	14	0	7
Guizotia scabra	2	5	16	25	13	95
Cyanotis barbata	0	0	15	20	155	3
Medicago sp.	61	72	62	64	31	113
Setaria pumila	0	0	43	24	11	19
Polygonium nepalense	52	88	49	91	0	9
Caylusea abyssinica	0	0	5	2	0	0
Plantago lanceolata	3	6	3	6	0	3
Nicandra physalodes	1	3	2	3	0	0
Gallium spurium	0	2	3	5	0	4
Sonchus oleaceus	0	0	9	19	0	0
Commelina bengahalensis	0	0	4	6	0	4
Scorpirus muricatus	0	0	11	37	0	9
Corrigiola capensis	0	0	1	0	0	0
Convolvulus arvensis	36	57	0	0	0	0
Cyperus rotandus	0	0	0	0	59	165

IWM = Integrated weed management (recommended plot), Farm = Farmers' practice

Conversely, intra-row spacing had no effect on most weed species distribution except *Erucastrum arabicum* and *Galium spurium*. Generally, weeds are among the indispensable yield limiting factors in maize production in the highland agro-ecology, despite the fact that weed species' distribution varies with cropping seasons and specific farm location which may be attributed to the extent of seed bank of weed species, and variation in fertility status of different farm plots. It is revealed in Tables 2 and 4 that weed species distribution was not consistent in the study periods.

The findings of the on-farm verification and appraisal of integrated weed management practices in high land maize in west Shoa (Meti, Mutulu and Toke) are presented in Table 5.

Occurrence of Weed Species in the Field

In the study of weed species distribution in maize fields, 660 was the highest number of plants per m^2 recorded at Mutulu for *Cyperus rotandus*, 596 plants m^{-2} for *Galinsoga parviflora* at Meti and 364 plants m^{-2} for *Polygonium nepalnese* at Toke on farmer practice plot (Table 3). This indicates that the lowest grain yield recorded in plots receiving farmers' practices was due to insufficient control of weeds. Rezene (1985) reported a similar finding that *Cyperus* species were noxious weeds for maize. In general, heavy infestation of both grass and broadleaf weeds undoubtedly contributed to grain yield reduction in maize.

Table 4. Effect of weed management practices and intra-row spacing on weed species distribution at Holetta, 2006 cropping season.

	Individual weed score (1–5)					
Weed mgt practice	***Snowdenia polystachi***	***Galinsoga parviflora***	***Galium spurium***	***Polygonum nepalense***	**General weed score (1–5)**	**Weed biomass (kg)**
W_1	1.0 b†	1.1 c	1.3 c	1.5 c	1.2 d	0.0 c
W_2	1.5 b	1.2 c	1.7 bc	1.4 c	1.5 cd	0.0 c
W_3	1.5 b	1.3 bc	2.0 b	1.4 c	1.8 c	1.0 b
W_4	1.0 b	1.6 b	1.6 bc	2.6 b	2.1 b	0.1 c
W_5	3.5 a	3.0 a	3.2 a	3.5 a	4.3 a	5.5 a
MEAN	1.7	1.6	2.0	2.1	2.2	1.3
CV (%)	50.9	30.2	26.0	24.3	22.3	54.7
Intra-row spacing						
S_1	1.5	1.6	1.8 b	2.0	2.0	1.1
S_2	1.8	1.7	1.8 b	2.0	2.2	1.1
S_3	1.6	1.5	1.8 b	2.0	2.2	1.6
S_4	1.9	1.7	2.3 a	2.3	2.3	1.4
	NS	NS	*	NS	NS	NS
MEAN	1.7	1.6	2.0	2.1	2.2	1.3
CV (%)	50.9	30.2	26.0	24.3	22.3	54.7

† Values followed by the same letters are not significantly different from each other. W_1 = Pre-emergence herbicide + once hand weeding at 30–35 DAE, W_2 = Pre-emergence herbicide + once hand weeding at 50–55 DAE, W_3 = Pre-emergence herbicide only, W_4 = Twice hand weeding at 30–35 and 50–55 DAE, W_5 = Weedy check, DAE = Days after emergence, S_1 = 20 cm intra-row spacing (66,666 plants ha^{-1}), S_2 = 25 cm intra-row spacing (53,333 plants ha^{-1}), S_3 = 30 cm intra-row spacing (44,444 plants ha^{-1}), and S_4 = 35 cm intra-row spacing (38,095 plants ha^{-1}), CV = coefficient of variance.

Table 5. Farmers' and recommended weed management practices in maize during 2005 and 2006.

Control methods	Farmers' practice	Recommended practice
Tillage	2–3 plowings	3 Plowings: 1st plowing during the dry season to eliminate perennial weeds; 2nd before planting to control already emerged weeds, and; 3rd at planting to prepare a seedbed
Competitive cropping and husbandry	Planting after the onset of rain, variable fertilizer, spacing, seed rate and seeding depth	Planting: soon after the land preparation after the rain onset at 30 cm × 75 cm spacing, 125 kg ha^{-1} urea + 150 P_2O_5 fertilizer, sowing Hora at 25 ha^{-1} rate evenly at 5–7 cm depth
Hand weeding and hoeing	Hoeing, inter-row cultivation, hand pulling and slashing variably	1st weeding: hoeing/hand pulling, at knee height 2nd weeding: slashing before flowering
Chemical application	No application	Lasso+Atrazine as pre-emergence

Yield and Yield Components of Maize as Affected by Weeds

Except for stand count, the other grain yield and yield components under recommended practices were greater than farmers' practice at all sites and years (Table 6). Besides, weed control practices stimulate weed seed germination and reduce the seed bank and subsequent weed density (Johnson *et al.*, 1989). Since farmers sow at a high population density of maize to reduce risk of crop failure, the stand count was higher in farmers' plots as compared to recommended practices. Averaged over location, grain yield of plots receiving recommended practices was increased by 92% for highland maize (Table 6). Assessment of economic feasibility, indicated that the marginal rate of return of plots receiving recommended practices was 662 % greater than farmers' practice for maize (Table 7).

In general, integrated weed management packages on all plots and locations provide better grain yield and weed control efficiency than the traditional farmers' practice in West Shewa Zone. This was confirmed during farmers' field day assessment. Therefore, farmers having similar agro-ecologies can adopt the technology for more productivity of maize.

Conclusions

In conclusion, it is evident that maize production and productivity is immensely affected by weed infestation in the central highland agro-ecology of the country. Along with technological advancement in maize variety development, latest information in agronomic management practices in maize is crucial. Current research information reviewed in this paper is very rare despite the current expansion of the crop. The dynamic nature of weed species' distribution and infestation demands intensive research endeavor. Hence, integrated weed management in this regard is an indispensable approach to regulate weed population density below that which causes economic loss to maize productivity. Therefore, future research work should regularly emphasize the screening of the latest herbicide chemicals along with different weed management practices to identify alternative recommendations which are environmentally safe and economically feasible. In the absence of the latest information of appropriate weed control measures, it is hardly possible to maximize grain yield due to maize technologies developed by breeders. Moreover, research information of one or two years is not comprehensive enough as reviewed in this paper. Therefore it is pertinent to periodically make an assessment and monitor weed species' distribution and extent of damage at representative locations, within the context of integrated weed management approach.

Gaps And Challenges

- The chemical weed control studies mainly focused on screening of products for sole application rather than as part of an integrated weed management approach.
- Invasive weeds like *P. hystrophorus* are gradually creeping into western region maize growing areas of Ethiopia.

Table 6. Average grain yield and yield components of maize during 2005 and 2006.

									% Increase							
Treatments	Yld (kg ha^{-1})	StC	Ph (cm)	EarH (cm)	Lines ear^{-1}	Seeds ear^{-1}	TGW (g)	CBm (kg ha^{-1})	Yld (kg ha^{-1})	StC	Ph (cm)	EarH (cm)	Lines ear^{-1}	Seeds ear^{-1}	TGW (g)	CBm (kg ha^{-1})
Rec. practices	4,533	284	253	16	13	411	221	1,114	92	-21	15	23	8	44	1	4
Farmers' practices	2,367	360	221	13	12	285	219	1,067	–	–	–	–	–	–	–	–

StC = stand count, Ph = plant height, EarH = ear height, TGW = thousand grain weight, Rec. practices = recommended practices.

Table 7. Average of the marginal analysis for integrated weed management practices in West Shewa during 2005 and 2006.

Treatments	Costs that vary (Birr ha^{-1})	Marginal costs (Birr ha^{-1})	Net benefits (Birr ha^{-1})	Marginal net benefits	(Birr ha^{-1})	MRR (%)
Recommended practices	Maize	2,316	–	12,990	–	662
Farmers' practices	Maize	1,245	1,071	5,902	7088	

MRR = marginal rate of return

Future Intervention Areas

- Developing integrated crop and weed management methods through a multi-disciplinary approach should be given due emphasis (integrating herbicide commercial products with cultural weed control practices) for major maize growing areas of Ethiopia.
- Efforts need to be made to create better awareness on the weed problem in major maize growing areas of the country.
- Involving farming communities in weed science research and development using new participatory approaches such as farmer research groups (FRG) and farmer field schools (FFS) should receive due emphasis.

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Striga Management in Maize Production in North Western Ethiopia: Review of Research Results

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Introduction

Maize is one of the most important cereal crops in Ethiopia, and grows almost in all parts of the country (CSA, 2010). Despite its importance in the country, there are a number of constraints limiting maize production, such as disease, insects, weeds (annual, perennial, non-parasitic and parasitic) (Firdu, *et al.,* 2002) and soil fertility. Among the biotic constraints, the noxious parasitic weed *Striga* spp. is a major limiting factor affecting maize production.

Striga also attacks millet, sorghum, upland rice and napier grass throughout sub-Saharan Africa from the high plateau of east Africa where farmers struggle to survive on tiny fields of maize, to the arid savannas of northern Nigeria where they rely on sorghum. African farmers today are fighting a losing battle against the striga effect (Kanampiu *et al.,* 2003). There are about three striga species; namely, *Striga hermonthica, Striga asiatica* and *Striga aspera* and all three of them exist in Ethiopia. In particular, *Striga hermonthica* is the most widespread species, occurring in northern, western, central and eastern parts of Ethiopia (Kassa *et al.,* 2002; Parker, 1991). *S. hermonthica* is a root parasite that infects cereal crops in sub-Saharan Africa. It constitutes the most important biological constraint to cereal production and accounts for more than 50% of the yield loss in the region. This yield loss affects the livelihood of about 300 million people in sub-Saharan Africa (Parker, 1991).

A survey undertaken during 1997 showed the existence of both *S. hermonthica* and *S. asiatica* in maize fields with the former being widespread and the latter having localized importance. The highest (95%) and lowest (1%) striga incidence levels have been recorded in Pawe and Dera districts, respectively (Kassa *et al.,* 2002). To alleviate this problem, different striga management research activities have been conducted in the Metekel zone of north western Ethiopia. Hence, the objective of this paper is to review research results for striga management and suggest the way forward.

Striga Management Options

Striga control using striga resistant maize genotypes

A set of striga resistant hybrid genotypes was evaluated at Pawe Agricultural Research Center in collaboration with the International Institute of Tropical Agriculture (IITA) during 2009 and 2010 cropping season in a striga free field and 2010 cropping season in a striga infested field to identify adaptable striga resistant maize genotypes.

Under artificially striga-infested field conditions the highest yield was obtained by entries 0601-6STR (5.3 t ha^{-1}), 0804-7 (5.1 t ha^{-1}), 0501-1STR (4.7 t ha^{-1}) and 0501-2STR (4.5 t ha^{-1}), however, the standard check, BH540, gave a yield of (0.5 t ha^{-1}) (Table 1).

Table 1. Summary of means for grain yield and other agronomic traits of International Institute of Tropical Agriculture (IITA) striga resistant hybrids in striga-infested field at Pawe, 2010.

Entry	MFLW	FFLW	PHT	EHT	CO1	CO2	Yield (t ha^{-1})
0502-5STR	73.3	77.5	171.3	80.3	4.8	6.9	1.7
0804-2	73.0	76.5	183.3	86.3	3.2	5.3	2.8
Check(BH540)	73.0	78.0	162.8	72.0	7.9	8.1	0.5
Oba Super I	72.8	80.3	185.8	83.3	5.1	7.1	0.5
0804-6	72.8	77.0	172.8	81.0	4.0	5.3	2.9
0804-3	72.5	76.0	192.3	92.5	4.4	7.5	3.3
9022-13	72.5	75.3	172.8	77.5	6.1	7.5	1.1
8338-1	71.5	85.0	188.5	66.5	7.5	8.8	0.0
0602-1STR	71.5	74.5	194.5	92.5	5.6	8.0	3.1
0804-7	71.0	74.0	188.5	94.0	5.4	7.3	5.1
0702-1STR	70.8	74.5	161.0	72.5	4.8	7.5	1.9
0501-2STR	70.5	73.3	209.3	96.0	7.0	8.0	4.5
0702-2STR	70.0	72.0	218.0	97.8	7.4	8.9	2.5
0501-6STR	69.3	71.8	198.5	98.0	8.3	10.3	4.0
0501-1STR	69.0	71.0	176.8	83.5	7.0	9.4	4.7
0601-6STR	69.0	71.0	210.0	108.5	6.3	9.0	5.3
CV %	3.2	4.7	14.6	15.0	25.5	16.6	38.7
$P \leq 0.05$	ns	**	ns	**	***	***	***

MFLW = male flowering, FFLW = female flowering, PHT = plant height, EHT = ear height, CO1 = striga count at 8th week, CO2 = striga count at 10th week, ns = not significant, ** = significant at $P \leq 0.01$, *** = significant at $P \leq 0.001$, CV = coefficient of variance.

Under striga-free field conditions the highest yield was recorded by entries 0804-7 (9.5 t ha^{-1}), 0501-6STR (9.4 t ha^{-1}), 0804-2 (8.6 t ha^{-1}), 0501-1STR (8.5 t ha^{-1}), 0601-6STR (8.4 t ha^{-1}), 0804-3 (8.4 t ha^{-1}), 0501-2STR (8.2 t ha^{-1}), 0502-5STR (8.1 t ha^{-1}) and the standard check, BH540 (7.1 t ha^{-1}) (Table 2). The results showed considerable evidence for better performance of the genotypes both under striga-free and striga-infested fields.

Striga control with imazapyr resistant (IR) maize genotypes

Striga infestation is a consequence of mono-cropping with cereals, which host the parasite, and declining soil fertility, which weakens the host plant to striga attack. As a result of these cropping practices, striga-infested areas have developed very high levels of long-lived striga seeds in the soil with only some breaking dormancy each season when stimulated by crop exudates (Kanampiu *et al.*, 2003).

CIMMYT, in collaboration with the Weizmann Institute of Science (Israel), has developed a unique product for striga control in maize. It combines low-dose imazapyr (a systemic ALS-inhibiting herbicide) seed coating and imazapyr-resistant (IR) maize seed that leaves a field virtually clear of emerging striga for the whole season. The new technology relies on herbicide resistance that was derived from a naturally occurring gene in maize and made available to CIMMYT (Kanampiu *et al.,* 2003).

Only a small quantity of imazapyr (as little as 30 g) delivered in this manner acts at the time of striga attachment to the maize root and prevents the exertion of phytotoxic effect of striga on the maize plant which usually occurs even before emergence of the striga from the soil. Additionally, imazapyr that is not absorbed by the maize seedling diffuses into the surrounding soil and kills un-germinated striga seeds (Kanampiu *et al.,* 2003).

The African Agricultural Technology Foundation (AATF) in collaboration with other stakeholders such as the Western Alliance for Technology Evaluation (WeRATE) and private seed companies are spearheading and facilitating the dissemination of imazapyr-herbicide resistant maize varieties (IR-maize) in western Kenya (Manyong *et al.,* 2008).

A series of experiments have been conducted at Pawe Agricultural Research Center in collaboration with CIMMYT since 2001 to identify IR-maize genotypes that can adapt to the area. All the chemically treated hybrid and open-pollinated variety (OPV) maize cultivars tested over the past years showed a higher yield than the locally cultivated maize cultivars under striga-infested plots (Fig. 1).

During the 2006/07 cropping season the mean yield reduction of genotypes due to striga infestation ranged on average from 1.0 to 2.7 t ha^{-1}. The average percent reduction in yield for the IR maize genotypes was 40.4% whereas for the standard check, WH403, it was 65.0%. Under striga-free conditions, the standard check (WH403) gave the highest mean yield (4.2 t ha^{-1}) but with only 3.4% yield advantage over the highest

Table 2. Summary of means for grain yield and other agronomic traits of International Institute of Tropical Agriculture (IITA) striga resistant hybrids in striga-free field combined over two years; 2009 and 2010.

Entry	MFLW	FFLW	PHT	EHT	Yield
0502-5STR	66.1	68.1	233.6	112.7	8.1
0804-2	66.1	67.5	242.1	116.9	8.6
Check(BH-540)	64.9	68.0	249.4	118.2	7.1
Oba Super I	67.0	68.5	232.9	111.7	5.3
0804-6	65.7	67.7	233.1	116.0	7.6
0804-3	64.6	66.5	245.5	114.9	8.4
9022-13	65.5	67.4	225.6	116.7	6.6
8338-1	63.0	66.0	239.9	96.6	5.1
0602-1STR	67.0	68.9	237.2	112.2	7.1
0804-7	65.0	67.0	243.6	118.2	9.5
0702-1STR	63.4	65.5	220.1	98.4	5.7
0501-2STR	63.7	66.0	241.1	113.4	8.2
0702-2STR	65.0	67.0	225.5	107.4	7.4
0501-6STR	64.1	66.2	245.1	125.7	9.4
0501-1STR	63.4	65.2	241.7	115.0	8.5
0601-6STR	63.5	66.0	240.6	122.1	8.4
CV %	2.7	2.5	4.7	9.5	17.7
$P \leq 0.05$	**	**	**	***	***

MFLW = male flowering, FFLW = female flowering, PHT = plant height, EHT = ear height, ns = not significant, ** = significant at $P \leq 0.01$, *** = significant at $P \leq 0.001$, CV = coefficient of variance.

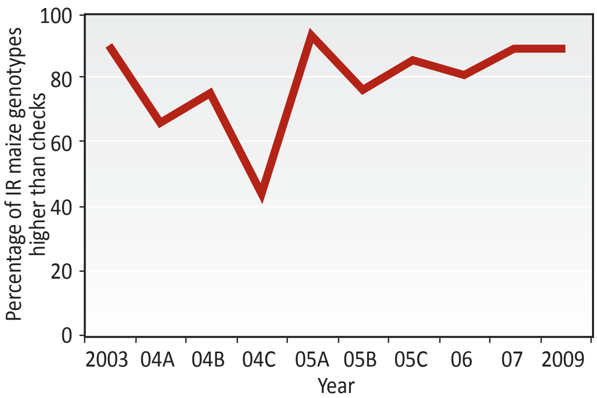

Figure 1. Performance of imazapyr resistant (IR) hybrid and open-pollinated variety (OPV) maize genotypes tested in Pawe since 2003. (A, B and C indicate the different set of experiments conducted in the same year).

yielding IR genotype, CML445/CML390/CML373 (4.1 t ha^{-1}). Whereas under striga-infested conditions, the highest yielding IR genotype, CML445/CML390/CML373 (2.4 t ha^{-1}) had a yield advantage of 86.5% over WH403 (0.6 t ha^{-1}) showing superiority of IR maize genotypes under striga infestation.

Based on their previous performance a total of 10 IR maize genotypes including check Gibe1 were evaluated both in the striga-infested and striga-free fields during the 2009 cropping season (data not shown). In the striga-infested field the maximum yield was obtained from ECA-VE-206 (2.5 t ha^{-1}) and lowest yield was recorded from Gibe1 and ECA-VL-20 (1.0 t ha^{-1}). Whereas, in the striga-free field the highest yield was recorded by Gibe1 (8.5 t ha^{-1}).

Slow release imazapyr formulations to control *Striga hermontica*

A different type of imazapyr formulation has a different response for high rainfall areas like Pawe. Identifying the best slow release imazapyr formulation that highly suppresses *S. hermonthica* severity, and suits the high rainfall areas is very important. Four new slow release imazapyr formulations namely; DEAE cellulose (DEAE), PEICellulose (PEICell), PEICelluloseCapped (PCA) and PEI Gell (Gel) were used at 5 imazapyr levels; 0, 15, 30, 45, and 60 g ha^{-1}. Imazapyr technical grade (98.7%) at the same rate was also included for comparison to make a total of 25 treatment combinations. IR-hybrid maize (CKT026065) was coated with these formulations using Murtano dust as a carrier.

The experiment was laid out in a (5 × 5) simple lattice design with two replications during 2007 cropping season. Each treatment was planted in 5.1 m long four rows 75 cm apart and 30 cm between plants. After thorough land preparation, sowing was done with two maize seeds per hill thereby each planting hole was infested with one spoon of striga seed. The rate and method of striga infestation was followed as per the method developed by IITA. Seedlings were thinned out to maintain single seedlings per hill together with the first weeding three weeks after emergence. Fertilizer was applied at the rate of 100 kg ha^{-1} of DAP and 50 kg ha^{-1} urea at planting and 50 kg ha^{-1} urea added at knee height. Striga counts were made every two weeks beginning from two weeks after planting until the fourteenth week before harvest. Yield and other agronomic parameters were collected and grain yield per hectare was calculated at 12.5% moisture content. Analysis of variance was carried out to see the difference between the different treatments for grain yield and to observe the effectiveness of the slow release nature of different formulations on the germination of striga.

Among all the 25 different types of slow release imazapyr formulation tested, 30 DEAE showed the highest yield at both Pawe and Manbuk areas (Tables 3 and 4) with a relatively minimum number of striga count, hence these formulations can also be recommended for high rainfall areas.

Cropping system

A field experiment was conducted at Pawe Agricultural Research Center (PARC) during 2004 and 2006 cropping seasons to select the best-suited food and forage legumes that can reduce striga infestation level and decrease maize yield loss. Five different food and forage legumes; namely, soybean (*Glysin max*), cowpea (*Vigna unguculata*), groundnut (*Arachidis hypogea*), silver-leaf (*Desmodium uncinatum*) and green-leaf (*Desmodium intortum*) were intercropped with maize in two cropping patterns; inter-row and intra-row planting on a striga-sick plot. To maximize reliability of striga infestation the plots were infested artificially with locally collected striga seeds. Maize varieties, BH530 in 2004 and BH540 in 2006 cropping season were used. The experiment was laid out in a randomized complete block design (11 treatments including the sole maize) in three replications. The result revealed maize-cowpea inter-row cropping supports the lowest striga number (4.7) whereas, maize-silver leaf inter-row cropping supports the highest striga number (12.5) over the two cropping seasons. The highest yield was obtained in maize-green leaf inter-row cropping (3.2 t ha^{-1}) and the lowest yield was observed in maize-silver inter-row cropping system (Table 5).

Conclusion

The problem of striga remains one of the major constraints for maize production. Different control options have been exercised to reduce the damage caused by striga. As presented above, all striga management options showed promising results. Of all the options, it seems that striga control using resistant genotypes is preferable because of ease of adoption by seed producers and farmers. However, further evaluations of striga resistant hybrids and OPVs both on striga infested and free fields are necessary to identify high yielding genotypes. Generally, since a single component of striga management cannot give complete protection, integrated approaches which are

Table 3. Mean yield of maize on striga infested fields at different formulations of imanzapyr, in Manbuk.

Treatment	Yield (t ha^{-1})	Striga 8 weeks	Striga 10 weeks	Striga 12 weeks	Striga 14 weeks	Mean striga
30 DEAE	2.9	0.0	28.7	49.7	66.7	36.3
15 PEI CELL	2.0	0.0	24.0	48.3	51.0	30.8
60 98.7% IMAZAPYR	2.0	0.0	11.0	27.0	51.3	22.3
60 PCA	1.9	1.0	13.7	63.7	67.3	36.4
15 GEL	1.9	0.0	8.7	27.7	43.3	19.9
45 PCA	1.8	2.7	11.7	29.0	44.3	21.9
30 98.7% IMAZAPYR	1.5	2.0	18.3	48.0	66.0	33.6
30 PCA	1.4	4.0	24.7	79.7	75.0	45.8
60 GEL	1.4	1.3	7.0	24.7	55.3	22.1
30 PEI CELL	1.4	0.3	30.7	54.0	86.0	42.8
45 PEI CELL	1.4	0.7	11.7	38.0	49.0	24.8
60 PEI CELL	1.4	1.0	30.7	80.3	87.0	49.8
0 Murtano	1.4	0.0	11.0	27.0	51.3	22.3
60 DEAE	1.3	3.3	16.7	50.0	66.7	34.2
0 MURTANO	1.2	0.7	13.3	43.7	87.7	36.3
0 MURTANO	1.2	1.0	22.7	59.0	56.7	34.8
30 GEL	1.1	1.7	19.7	64.3	86.3	43.0
15 98.7% IMAZAPYR	1.1	0.0	19.0	63.3	69.0	37.8
45 DEAE	1.1	1.0	5.3	32.0	45.3	20.9
45 GEL	1.0	0.0	10.7	73.3	76.7	40.2
0 MURTANO	0.8	0.7	32.0	44.0	53.7	32.6
15 PCA	0.7	1.7	11.7	29.7	39.7	20.7
45 98.7% IMAZAPYR	0.7	0.7	27.3	47.3	92.3	41.9
15 DEAE	0.6	3.3	22.0	57.7	65.3	37.1
0 MURTANO	0.0	0.7	24.3	56.0	77.0	39.5
MEAN	1.4					

Table 4. Mean yield of maize on striga infested fields at different formulations of imanzapyr, in Pawe.

Treatment	Yield (t ha^{-1})	Striga 8 weeks	Striga 10 weeks	Striga 12 weeks	Striga 14 weeks	Mean striga
30 DEAE	28.0	11.3	36.0	88.0	60.3	49.0
45 PCA	19.0	2.0	33.3	94.3	51.0	45.2
15 98.7% IMAZAPYR	18.3	3.0	20.7	82.0	49.3	38.8
60 DEAE	18.3	1.3	24.3	138.0	88.3	63.0
0 MURTANO	18.0	29.0	40.7	114.7	62.0	61.6
30 PCA	17.7	0.3	18.7	65.3	68.7	38.3
30 98.7% IMAZAPYR	17.3	2.3	7.7	47.0	25.0	20.5
60 GEL	16.3	1.7	24.7	32.7	28.0	21.8
15 PEI CELL	16.0	16.7	20.7	79.7	50.0	41.8
60 PCA	15.3	3.7	8.0	62.3	54.7	32.2
0 MURTANO	15.0	12.0	42.3	91.7	60.3	51.6
60 PEI CELL	12.7	0.0	29.0	80.7	76.7	46.6
30 PEI CELL	12.7	1.3	8.0	61.0	42.7	28.3
60 98.7% IMAZAPYR	12.3	2.3	26.7	60.0	49.7	34.7
45 DEAE	12.0	12.7	36.7	112.3	89.3	62.8
45 PEI CELL	11.0	0.0	11.7	56.3	76.7	36.2
15 GEL	10.3	2.3	21.0	57.3	60.3	35.3
15 PCA	10.0	0.0	19.0	63.3	69.0	37.8
0 MURTANO	10.0	9.3	41.0	75.0	64.3	47.4
30 GEL	9.0	4.0	13.7	76.7	44.7	34.8
45 GEL	8.7	4.0	26.3	102.7	57.3	47.6
0 MURTANO	8.7	5.7	14.3	76.7	46.0	35.7
30 GEL	8.0	7.0	47.0	123.3	75.0	63.1
45 98.7% IMAZAPYR	8.0	4.3	41.3	120.3	98.0	66.0
0 MURTANO	6.0	5.0	27.7	90.3	62.7	46.4
MEAN	13.5					

economically feasible and environmentally friendly, that can reduce both the damage of the striga and seed bank in the soil should be emphasized.

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Table 5. Maize yield and average striga count of each treatment for the year 2004 and 2006 at Pawe.

Treatments	2004 Striga count	2004 Maize yield (t ha^{-1})	2006 Striga count	2006 Maize yield (t ha^{-1})	Combined 2004 and 2006 Striga count	Combined 2004 and 2006 Maize yield (t ha^{-1})
M/Silver leaf inter-row	5.8ab	1.0b	5.8a	1.8a	12.5a	1.4a
M/Silver leaf intra-row	5.4abc	1.4ab	2.1a	3.6a	8.0ab	2.5a
M/Soybean inter-row	6.6a	1.8ab	2.8a	2.1a	10.5ab	1.9a
M/Soybean intra-row	4.1abcd	2.0ab	4.4a	2.2ab	8.8ab	2.1a
M/Groundnut inter-row	3.8bcd	3.2a	4.0a	2.2a	8.6ab	2.7a
M/Groundnut intra-row	4.1abcd	1.4ab	2.6a	3.0a	6.7ab	2.2a
M/Cowpea inter-row	3.3cd	2.2ab	1.1a	2.2a	4.7b	2.2a
M/Cowpea intra-row	2.5d	1.1b	2.5a	2.0a	5.1b	1.5a
M/Green leaf inter-row	4.3abcd	3.1a	3.3a	2.9a	8.0ab	3.0a
M/Green leaf intra-row	4.5abcd	2.5ab	4.4a	2.5a	9.8ab	2.5a
Sole maize (control)	5.0abc	2.1ab	5.8a	2.3a	11.1ab	2.2a
CV (%)	29.1	50.1	69.9	55.4	49.3	55
Grand mean	4.5	2.0	3.5	2.4	4	2.2
Probability level	0.1	0.1	0.1	0.1	0.1	0.1
R-Squared	0.6	0.64	0.36	0.19	0.32	0.27

Means with the same letter are not significantly different at P ≤ 0.05. M = maize, CV = coefficient of variance.

Review of Agricultural Mechanization Research Technologies in Maize Production in Ethiopia

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Introduction

The farming practice in Ethiopia is of a subsistence nature, where more than 90% of the cultivated land is in the small farm category (CSA, 2010). Agricultural production and post production mechanization for the different steps such as soil tillage, planting, harvesting, threshing and post harvest handling in the country is in its early stage of development, characterized by the use of traditional and obsolete tools/implements and practices. The traditional plough (*maresha*) and the production techniques are outdated and have been identified as bottlenecks to crop productivity because of their high labor demand, longer working hours and low quality of work.

Though maize production area, total production and productivity in Ethiopia have increased over the years, it requires the use of improved farm tools and equipment with a view to reduce the drudgery of the human beings and draft animals, enhance the cropping intensity, increase greater precision and timelines of utilization of various inputs and reduce losses at different stages of crop production.

In the past five decades, there have been several attempts by different institutions to introduce small-scale agricultural mechanization technologies to various farming communities in the country with the end objective of enhancing the overall productivity and production with the lowest cost of production. Different implements like ploughs, harrows, planters and threshers were developed and some were introduced from elsewhere and given out to the farming community. However, the use of these implements for most agricultural operations is unsatisfactory throughout the country due to various reasons. The minimal use of improved implements could be due to many constraints like non availability at their place of work, lack of timely and seasonal use of implements, poor financial provision for investment in farm implements, lack of sustained promotion and many such other things. Therefore, creating awareness and interest in improved agricultural mechanization technologies among potential stakeholders such as policy makers, non-government organizations (NGOs) and manufacturing companies will be critical to effectively carry out different field operations that are meant for increased agricultural productivity and reduction of crop losses.

Research Achievements

Several types of implement prototypes, both from abroad and from different sources in the country were collected and tested in the field with subsequent modifications made to the implements to make them both technically and economically acceptable to the small-scale farmers. Some of the successful prototypes developed/improved so far in the country include various tillage implements, maize shellers, simple storage methods and by-product processing equipment.

Tillage and improved implements

Animal drawn tillage implements such as *Erf* and *mofer* attached moldboard plough, row planters, inter-row weeder, tie-ridger and ripper were developed as modifications or attachments to the traditional *maresha* plough (Melesse, 2000; Melesse *et al*., 2001). These implements were tested and evaluated both on-station and on-farmers' fields and found effective to contribute for a better work quality, reduced drudgery and increased productivity. Moreover, they improved timeliness of farm operations like land preparation and planting which favored the crop to fully utilize the available growing period.

Moldboard plough

Primary tillage is generally found to be necessary for creating a favorable root proliferation zone, enhancing water percolation and increasing porosity (aeration status) of the soil. The experiment conducted on plough type and tillage frequency for the production of maize in the dryland areas of Ethiopia showed 75%, 43% and 25% increase in grain yield of maize with the use of *erf* and *mofer* attached moldboard ploughs (Fig. 1) over the traditional plough when ploughing, once, twice and thrice, respectively (Melesse *et al*., 2001). An on-farm experiment with *erf* and *mofer* attached moldboard plough indicated a 12% maize grain yield advantage over the local *maresha* (Kidane, 1989). In a study carried out to evaluate and promote *erf* and *mofer* attached moldboard ploughs in three *woredas*: Bora, Adamitulu and Shalla between 2006 and 2008, quite encouraging responses were obtained, which further pushed the technology towards uptake. Farmers pointed out that the use of the new plough achieved complete ploughing in one pass thereby reducing tillage passes by 50%, hence farmers could get free time to do other activities. In addition, it resulted in improved tillage and seedbed preparation; increased water infiltration and timeliness in land preparation and weeding, reduced drudgery and savings in labor and time compared to the traditional plough. However, farmers suggested improvement work to correct the fast wear and tear of the shearer and avail the plough at a reasonable price (Endeshaw *et al*., 2009).

Tie-ridging

Water is a primary limiting factor for maize production in arid and semi-arid parts of the country, but this is often not necessarily due to low seasonal rainfall but rather to poor distribution of rainfall and large losses of water in runoff. Tie-ridging (furrow diking) is a technology that can reduce surface runoff, increase soil water storage, and is likely to benefit the crop in arid and semi-arid areas to reduce drought risk, increasing grain yield and ensure maize production in a drought year. The advantages of tie-ridging have been investigated (Kidane *et al*., 2001; Melesse, 2000, 2007; Melesse *et al.,* 2001; Tewodros *et al*., 2007) and have proven to be an effective practice for improving soil water availability and maize yield in semi-arid parts of the country both through formal on-station and farmers' participatory research. Hence, different tie-ridging techniques are being promoted as a rainwater harvesting technique in the moisture stressed agro-ecologies of the country. Evaluation of three implements: modified tie-ridger, the traditional plough and inverted Broad Bed Maker (BBM) for tie-ridging indicated that the modified tie ridger (Fig. 2) required a lower draft power, when tying the furrows considerably reduced the drudgery of the operation and was able to make a wider furrow compared to the rest of the implements (Melesse, 2007).

Strip tillage and sub-soiling

Conventional tillage systems often cause the formation of plough pans or hard pans that restrict infiltration and root growth. Sub-soilers developed as modifications to the steel mouldboard ploughs are heavy and made of expensive frames. Therefore, a simple sub-soiler was developed as a modification of the *maresha* plough (Melesse, 2000, Melesse *et al*., 2001). Melesse (2007) studied three tillage systems: strip tillage with and without sub-soiling and the traditional tillage system of 3–4 times ploughing using the *maresha* plough and a sub soiling implement modified from the same plough at two *woredas* in the Central Rift Valley of Ethiopia. Strip tillage with sub-soiling followed by strip tillage without sub-soiling performed better than traditional tillage in surface runoff, transpiration, water productivity and grain yield of maize.

Row planter

Manual placement of seeds and fertilizer required three people (one operating the *maresha* plough to open furrows, a second person to drop seeds and a third person to drop fertilizer) and took 26 h ha^{-1} (Melesse, 2007). An animal drawn single row planting equipment used for seeding and band placement of fertilizer has been developed at Melkasa Agricultural Research Center. The row planter was operated by only one person and it required only 12 h ha^{-1}. Thus, the maximum saving in man-hour (expressed as the product of the number of persons and time required to complete a given area) was 85%.

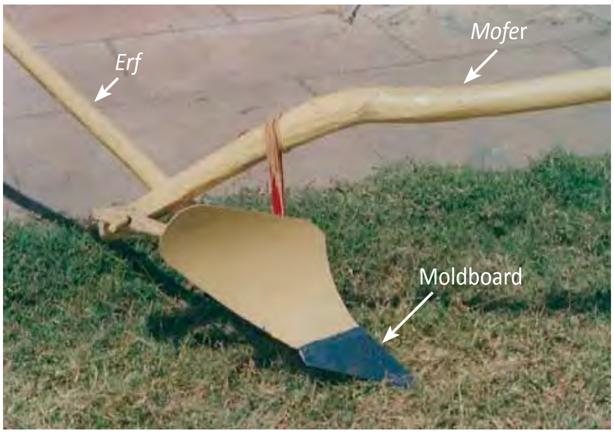

Figure 1. *Erf* and *mofer* attached to a moldboard plough.

Figure 2. Modified tie ridger.

Dry lime spreader

Soil acidity problems that are not suitable for growing crops are predominant in the western, northwestern and southern parts of the country, mostly on land where forests have been cleared and used for continuous cultivation without giving due consideration to deteriorating soil properties. According to the Ministry of Agriculture (MoA), 40% of the total arable land in Ethiopia is acidic, of which 15% is highly acidic. Problems associated with soil acidity include aluminum, manganese and iron toxicity and also phosphorous, calcium, magnesium and potassium deficiencies, and poor root development. For this challenge, the usual practice has been to add lime as an amendment to lower the acidity, especially in western Oromia where maize is the major crop. In this area, lime was added as an amendment and promising results were achieved, but liming above optimum pH level (6–7) may do more harm than good in that it may cause deficiencies of micro-nutrients. Under liming may also cause maltreatment. Thus, an appropriate lime spreader used to apply lime uniformly and easily in the fragmented small-land farms was developed by the Bako Agricultural Mechanization Research Center. Accordingly, for the application rate of 1–5 t lime ha^{-1}, the device had a field capacity of 0.3–0.4 ha h^{-1} and 90–97% application uniformity efficiency. In contrast, hand application had 50–55% application uniformity efficiency and performed 0.025–0.028 ha h^{-1}. In addition, it involved working by carrying the lime bag, being in the bending position and walking in a tiresome condition (BAMRC, 2005).

Post-harvest handling equipment/technologies

Even though the production of maize is increasing in Ethiopia, postharvest problems in terms of availability and access of appropriate harvesting, shelling and cleaning equipment and the lack of modern storage facilities are the major constraints in Ethiopia. As agricultural production is mainly practiced by small-scale farmers, maize is harvested pre-dominantly by detaching the cob from the plant in the field and is shelled, after hand husking, by either threading with animals on a platform, beating with a stick, rubbing one cob on the other or using the palm and fingers. After shelling, the grain is cleaned and stored in jute bags in their home or in traditional storage bins. These storage practices are incapable of providing and maintaining the storage requirements of the produce for long-term storage and consequently grain losses are high. In order to overcome the problems encountered with the above methods, improved maize postharvest equipment and practices like different types of maize shellers (manually operated and engine driven), above ground storage structures, modified maize cob grinder for feed and corn cob carbonizer for charcoal making were recommended for use.

Maize sheller

The success of the shelling operation can influence other successive operations/processes such as storage life, quality, prevention of storage insect attack, nutritive value and germination capacity of the crop. The traditional shelling techniques are quite time consuming and monotonous. With the high amount of maize production and the trend of its increment, it is clear that these techniques are ineffective. Therefore, high yielding mechanical power driven (P.T.O or 12HP engine) maize shellers were developed at Bako Agriculture Mechanization Research Center (BAMRC) (Fig. 3). This sheller had 5–6 t h^{-1} shelling capacity with a very good shelling efficiency and insignificant grain loss.

Another engine driven (5–8 HP) maize sheller was fabricated by the Agricultural Mechanization Research team at Melkasa Agricultural Research Center (AMR-MARC). The field performance and demonstration trial of this equipment at Adami Tulu Jido kombolcha district in 2009 indicated that it had an average shelling capacity of 3.8 t h^{-1} using 12 people (a family of different age groups). To shell the same amount of maize grain it would have required six people and nine oxen for two days. The cost of shelling using hired threshers was estimated about 312 *Birr* for 2.4 tons. On the other hand, the cost of shelling using traditional method (hired human labor) was estimated 422 *Birr* for two days using six people and nine oxen (for free). So, the participating farmers in the trial preferred the implement for saving time, labor and money (AMR-MARC, 2009).

Figure 3. Bako engine/PTO driven maize sheller.

Presently motorized shellers, particularly the Bako sheller, have been under used in many parts of the country, owned by wealthy farmers and insignificantly serving some small-scale farmers on a rental basis. However, these motorized shellers on Ethiopian farms are out of reach of the rural peasant farmers that are characterized by small holdings and low income. Many farmers grow maize but could not afford the cost of acquiring motorized maize shellers because of their initial cost. Considering the social, economical and technical level of small-scale producers, hand cranked and pedal driven maize shellers were developed at Bako and Melkasa research centers, respectively (Fig. 4a, b). The net unit shelling cost of maize using this machine was decreased by half compared with that of those automated by fuel. They were constructed from locally available materials and their cost was very low and affordable. They had more than 0.4 t h^{-1} capacity, 99.2% threshing efficiency, and insignificant breakage and losses. Therefore, these shellers were more suitable for small-scale farmers, thereby helping to increase their income (AMR-MARC, 2001).

Storage methods

Losses in traditional on-farm bulk grain stores in Ethiopia are high. About 16–20% of the already harvested crop is lost due to the poor storage systems. In a recent loss assessment study, losses of 11.2% were found for maize after 13 months of storage in *gottera* (structure used in Ethiopia for on-farm bulk grain store). A study carried out to test three grain storage structures (UG – un-raised *gottera*, RG – raised *gottera* and MBS – mud brick silo) for a storage period of 6 months at Melkasa indicated that grain damage caused by insects, rodents and weevils was comparatively low (6.3%) in the raised *gottera* followed by mud brick silo (10.0%) and the highest damage was in the un-raised *gottera* (14.4%) (AMR-MARC, 2002). Similarly, an experiment conducted to compare the quality of maize stored in three different types of storage structures (locally made indoor storage or *gotta*, outdoor raised bed storage and mud silo storage) at Alafa in west Gojjam zone indicated 4.2%, 6.2% and 7.7% average percentages of grain loss for raised bed storage (Fig. 5), mud silo and *gotta*, for the storage period of 8 months, respectively (AMR-MARC, 2002). It was also reported that considerably higher broken maize kernels were observed in *gottas* and mud silo storages after 4 months of storage due to rats and crawling pests.

Prevention of stored grain losses in developing countries, which ultimately lead to food shortages and malnutrition, is currently of major importance.

Figure 5. Raised bed grain storage.

Figure 4. (a) Bako manual driven maize shellers (b) Melkasa Pedal driven maize sheller.

Chemical treatments are still widely used for the control of storage insects, but increased public concern over the adverse effect of toxic chemicals in food and the environment and the development of insect resistance to chemicals, necessitated for non-chemical stored product insect control methods. In view of this, a study on indigenous mud bin, polythene lined mud bin (hermetic structure) and assisted polythene lined mud bin (assisted hermetic structure as biogenerator for modified atmospheres) was conducted at Bako Agricultural Mechanization Research Center for storage of maize grain. Following 8 months of storage, high infestation of insects, moisture content change and significant difference in the germination capacity in the untreated storage was observed. Whereas low infestation of insects with no indicative change of moisture content, germination capacity and total grain mass was observed in both treated storages. There was significant difference between treated and untreated but this was not seen within modified atmosphere treatments. From the result obtained, a modified atmosphere storage system has good potential to replace conventional chemical treatments in controlling insect pests in the grain bins used by small-scale farmers in Ethiopia.

Crop storage efficiency depends on length of storage period, losses during storage (including quality deterioration) and storage volume. Storage facilities offer the opportunity to improve farm incomes by storing crops and selling at premium prices when demand outstrips supply later in the post-harvest period. As quality is an important determination of crop retail prices, effective storage is crucial to improve agricultural incomes and food security for small scale farmers. For storage to be effective, crop losses could be minimized by slight modification of traditional methods and using air-tight storage.

Modification of oil drum corn cob carbonizer

Oil drum carbonizer obtained from Ethiopian Rural Energy Source Development and Promotion Center was singled out to be verified so that it could be promoted around the Bako area. Initially, the material was designed (adopted) by the organization to produce charcoal from wood, however, the carbonizer was verified using corn cobs as an input material since the area is a potential maize growing zone and hence this by-product was abundantly available. Along with the verification trial, economic benefits of the output of the technology (cob charcoal) were evaluated against raw corn cob and wood charcoal. The result of the verification confirmed that the drum suited the charring of bare corn cob and the evaluation trial of the output showed that the technology was worth adopting and inspiring to keep up the promotional effort (BAMRC, 2005). The same report indicated that after the verification trial the charring drum and the working procedure were modified and consequently it was managed to increase the grain yield by 10% volumetrically and decrease the time of carbonization (charring time) by an hour with the conversion rate of 65%.

Conclusion

A number of technologies both in pre- and post-harvest mechanization have been developed over the past two decades. The technologies have great potential to increase productivity, reduce losses and improve income of farmers. But Ethiopian farmers could not have access to such improved/imported agricultural mechanization technologies because of lack of awareness for such technologies, high initial cost, unavailability of such technologies and many other reasons. Therefore, aggressive promotional work on the importance of using improved farm implements, government encouragement of entrepreneurs to produce improved agricultural implements and equipment, linking farmers with financial institutions and establishing a revolving loan from which the farmers can borrow money to buy implements is considered essential. It is also important to introduce small-scale efficient storage practices ensuring that the traditional grain storage structure is more airtight to minimize environmental hazards and extend the storage potential.

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Agro-ecological Suitability for Hybrid Maize Varieties and its Implication for Seed Systems

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Introduction

Production of maize in Ethiopia is increasing rapidly and it's an important crop in the country. This increment is as a result of improved high yielding varieties and other technologies. According to CSA (2009) the total production of maize in Ethiopia in 2008/09 was estimated to be four million tons. Though the production is increasing and the adoption of improved technologies is relatively better than other cereals, the number of improved maize varieties that are in the hands of farmers are limited (Dawit *et al.,* 2010). To disseminate these improved varieties to their appropriate recommended domains, where they can perform well, it is essential to identify and map the potential growing areas for the varieties so as to extend the production to wider and new areas where the varieties are not yet disseminated.

Different areas have different production potentials and constraints for particular uses. Good information about the potential for various uses is thus essential to land use planning (FAO, 1993). Appropriate decisions on crop production will avoid various risks associated with it. If one knows the potentials and constraints of the land, it will be easy to choose or develop appropriate technology and extend it to its appropriate zone. Geographic Information Systems (GIS) enable such different kinds of information to be assembled, combined, overlaid and mapped. It also enables easy updating and retrieval, and complex and tedious calculations on the data to generate tables and maps. This will enable us to know where and how much potentially suitable land is available for growing of crops as per their specific agro-ecological and other production requirements. It is, therefore, very important to identify and show the extent and distribution of areas of lands that are potentially suitable, or not, for the crop varieties.

Suitability studies have been recognized for a long time as part of planning wise cropping systems (FAO, 1976). Suitability modeling is finding increasing application in different agricultural production systems like crop dominant systems, pastoral systems and forestry production systems. Even nowadays, crop-variety level suitability modeling is becoming common in different parts of the world. For instance Friew (2003) conducted variety level suitability studies for different beans, maize and sorghum varieties which were developed under the Ethiopian national agricultural research system (NARS). In the same way, Betre (2003) studied lentil varieties in Ethiopia. In suitability modeling, different criteria are considered and the most commonly used are climate, soil, and topography information.

The main objective of this paper is to document the distribution of suitable areas for different maize varieties released by the Ethiopian NARS and those that are under production. This is expected to promote the demonstration and popularization, and also the distribution of seed of these varieties in their most suitable agro-ecologies.

Methodology

Data and data source

Soil (soil depth, drainage and texture):
Soil is one of the important factors determining the growth of maize. For this study soil depth, drainage and texture were taken as parameters for the analysis. For these layers, data were extracted from the digital soil database prepared by FAO in 1997 at a scale of 1:1,000,000 (FAO, 1997).

Climate (rainfall, temperature and length of growing period, LGP):
The most important climate data that were used in this study are rainfall, temperature and LGP. These data were taken from the Ministry of Agriculture (MoA). The raster data were prepared in a way that could be compatible with the other data in a GIS environment

Topography (altitude and slope):
Topographical data were used to incorporate slope and altitude information relevant to land suitability. For this study, the 200 m digital elevation model (DEM) and slope maps prepared by the Center for Development and Environment (CDE) and MoA (1999) were used.

Administrative boundary map:
This data was obtained from the CDE and MoA (1999) dataset and was used to define the extent of the different land resources of the country.

Infrastructure data:
In the same way as administrative boundary data, these data were obtained from the CDE and MoA (1999) dataset. Incorporating such data is very essential for extracting restricted areas from the analysis.

Maize varieties characteristics:
Varieties specific environmental requirements were prepared by gathering from secondary data sources, particularly variety registries of MoA (2010), FAO (1984) and various publications of the Ethiopian Institute of Agricultural Research (EIAR).

Land characteristics as evaluation:
In this study a GIS-based crop suitability study was undertaken by taking into account important land characteristics for evaluating the land against the maize varieties and land qualities for determining the degree of suitability level. The land characteristics that were used in this study are drainage, soil depth, texture, slope, LGP, altitude, temperature and rainfall. The overall suitability is expressed in three classes: highly suitable (HS), moderately to marginally suitable (MMS) and not suitable (NS). Moderately suitable and marginally suitable land was expected to have a crop yield of 60–80% and 40–60% of the yield under optimal conditions with practicable and economic inputs, respectively. Unsuitable (U) land was assumed to have severe limitations which could rarely or never be overcome by economic use of inputs or management practices (FAO, 1976; Dent and Young, 1981). The main factors' scale range that varied with varieties was the rainfall, elevation and temperature. All other variables were kept similar for all of the six varieties (Table 1). For the rest of the factors' range, the environmental requirements indicated for maize in FAO (1984) are used. In this study, larger towns, lakes and parks were assigned as restricted based on the corresponding existing digital datasets.

Approaches followed in determination of suitability maps

The GIS approach used in this study identifies input data for the land suitability models and develops a modeling procedure for processing and output presentation. Basically, the suitability model involved three steps: (i) identification of suitability factors, (ii) rating and ranking the suitability factors, and (iii) weighing the factors selected and finally implementing the suitability model. Digitized maps, the geographical distributions of soils, topography and climatic

Table 1. Biophysical factors considered for the suitability analysis.

Biophysical factors	Varieties	Highly suitable	Suitability classes Moderately to marginally suitable	Not suitable	Relative weight (%)
Altitude (m)	BH660	1,720–2,080	1,540–1,720, 2,080–2,260	<1540, >2260	18
	BH540	1,200–1,800	900–1,200, 1,800–2,100	<900, >2100	
	BH543	1,200–1,800	900–1,200,1,800–2,100	<900, >2100	
	BH670	1,840–2,260	1,630–1,840, 2,260–2,470	<1630, >2470	
	AMH800	1,940–2,360	1,730–1,940, 2,360–2,570	<1730, >2570	
	AMH850	1,960–2,440	1,720–1,960, 2,440–2,680	<1720, >2680	
Rainfall (mm)	BH660	1,100–1,400	950–1,100,1,400–1,550	<950, >1550	20
	BH540	1,040–1,160	979–1,040, 1,160–2,200	<979, >1220	
	BH543	1,040–1,160	979–1,040, 1,160–2,200	<979, >1220	
	BH670	1,100–1,400	950–1,100,1,400–1,550	<950, >1550	
	AMH800	1,040–1,160	979–1,040, 1,160–2,200	<979, >1220	
	AMH850	1,040–1,160	979–1,040, 1,160–2,200	<979, >1220	
Temperature (°C)	BH660	17–23	13–17, 23–25	<13, >25	12
	BH540	17–23	15–17, 23–25	<15, >25	
	BH543	17–23	15–17, 23–25	<15, >25	
	BH670	15–23	10–15, 23–25	<10, >25	
	AMH800	15–23	10–15, 23–25	<10, >25	
	AMH850	15–23	10–15, 23–25	<10, >25	
Length of growing period	BH660	S1-1 to S1-17,	D2i-1 to D2i-4, D1i-1 to D1i-2	S0-1 to S0-4,	18
	BH540	D2u-1 to D2u-3,		D3-1 to D3-4,	
	BH543	D2a-1 to D2a-3,			
	BH670	D1a-1 to D1a-3,			
	AMH800	D2a/DS1 to			
	AMH850	D2a/DS4			
Texture	All varieties	Loam, sandy loam	Clay loam	Sand, clay	8
Slope (%)	All varieties	0–8	8–15	>30	6
Effective soil depth (cm)	All varieties	>100	50–100	<50	
Drainage	All varieties	Well drained	Imperfect	Flooded, poor	10

parameters were captured together with attribute data (e.g., soil texture, soil depth) for each mapped soil unit. Overlaying was carried out using ArcGIS software in the model builder module. The results are presented as tables and maps. Overall suitability is recognized by weighted overlay approach. Each factor layer has been given influence weight and scale with total sum of one based on professional opinion and review of relevant materials. The biophysical factors considered for suitable land for the cultivation of the different maize varieties are presented in Table 1. The main factors' scale ranges that varied with varieties were the rainfall, elevation and temperature. All other variables were kept similar for all of the six varieties. The weighted overlay combination has three classes, which are (i) highly suitable, (ii) moderately to marginally suitable and (iii) unsuitable. An area to fall in each class, overall suitability analysis is undertaken by combining of each factor suitability class according to their weight.

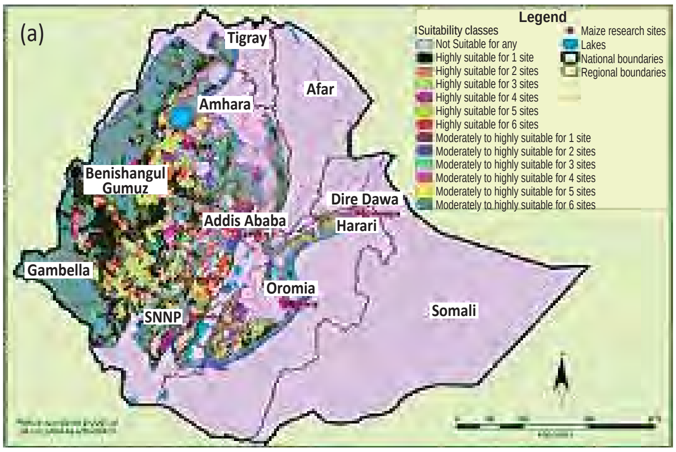
Suitable Areas for Popular Hybrid Maize Varieties by Region

According to the suitability analysis, BH540 and BH543 maize varieties are taking the leading position in potential area coverage. Each of these varieties potentially covers 9,875,652 ha of land. BH660, BH670, AMH850 and AMH800 are covering 6,489,600, 6,656,948, 5,895,532 and 5,450,140 ha of land, respectively (Table 2). The total area that would be highly suited for at least one of the above six varieties is 18,033,760 ha which is around 15% from the total land of the country (Fig. 1). It should also be noted that since this study depicts the potential area for the above varieties, it does not mean that this much land is free and available for growing maize varieties since the areas may already be occupied by another use or can be used for another alternative use. Though the summation of the highly suitable areas of all these varieties is 44,243,524 ha, the effective area is only 18,033,760 ha due to the overlapping/competing growing area of these varieties.

From a location point of view, all six varieties are best suited to the western part of the country. Specifically Amhara, Beneshangul Gumze, and eastern Gambela, western Oromia, western Southern Nations, Nationalities, and Peoples (United Nations; SNNP), Tigray and some pocket areas of the Afar regions. Oromia, SNNP and Amhara regions ranked from one to three in terms covering larger areas (Table 3).

Table 2: Potential area (ha) for maize varieties.

Hybrid maize varieties	Unsuitable	Restricted	Moderately to marginally suitable	Highly suitable
BH660	73,683,752	2,058,900	30,346,620	6,489,600
BH540	78,337,928	1,971,052	22,394,324	9,875,652
BH543	78,337,928	1,971,052	22,394,324	9,875,652
BH670	70,456,468	2,073,784	33,391,572	6,656,948
AMH800	71,331,336	2,024,452	33,772,804	5,450,140
AMH850	69,768,288	2,025,976	34,888,924	5,895,532



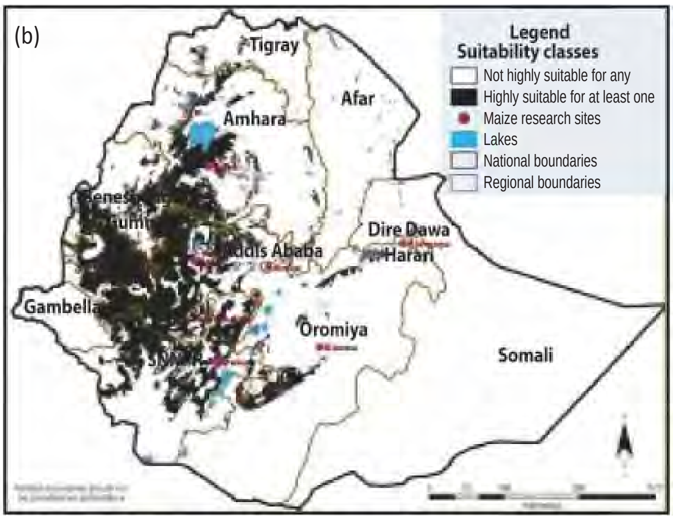


Figure 1. (a) Map showing potential areas for growing one or more of the hybrid maize varieties (BH660, BH540, BH543, BH670, AMH800, and/or AMH850), (b) overall highly suitable areas at least for one of the six hybrid maize varieties.

The main reason for the suitability of the western part of the country is mainly due to climate and topographic condition of the area. It is well known that this part of the country receives higher amounts of rainfall with good temperature conditions throughout the growing season. On top of this, the topography situation is highly matched with the requirement of maize varieties. This matching condition of the climatic elements with topography creates a synergetic effect for best suiting of the maize varieties in the area. This is also in line with the maize production belt of the country.

The trends in the distribution of the potential areas to grow the different types of maize hybrids, depicted in Fig. 2, show that there is clear distributional difference among the BH6, BH5 and AMH series but similarity within each series.

The clear difference in the distribution of suitable areas for the different series of maize hybrids implies the need for better targeting in the distribution of seeds produced in the country. One of the main reasons stated for seed leftovers under the condition where the demand is higher than the supply is associated with the limited efficiency of targeting of distribution (Dawit *et al.,* 2010). On the other hand, the similarity of the suitable areas for the varieties under each series implies the need for distribution of the varieties as an option for farmers to choose based on the preference between the varieties under each series.

In general, the amount of certified seed produced for maize hybrids is below 50% of the official demands reported by regions (Dawit *et al.,* 2010). Along with this shortage, the proportion of seed produced for these varieties as compared to the proportion of suitable land size fitting for the different maize hybrids confirms the argument that there is a serious problem in targeting the volume of seed produced (Table 4). The huge shortage in supply of BH540 as compared to BH660 for the 2011 production also confirms the seed production targeting problem. Studies associate the problem of production targeting with the poor seed demand assessment in the country (Dawit *et al.,* 2010; Dawit, 2010). The limited production of the maize hybrid seeds targeted for highland agro-ecologies (AMH maize hybrids) as compared to the vast highly suitable land available in the country shows the forgone opportunity in increased production and productivity from highland areas of the country.

Table 4: Amount of certified seed produced for maize hybrids' highly suitable areas by region for hybrid maize varieties (in ha).

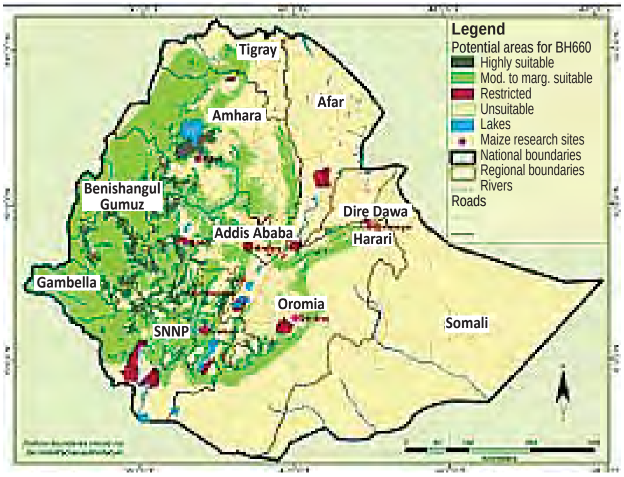
Maize hybrids	Certified seed produced (2010)	Share of produced seed by variety	Share of produced seed by hybrid series (%)	Share of total suitable areas (%)
BH660	56,419	55	56	15%
BH670	400	1		
BH540	35,199	34	44	22%
BH543	10,344	10		
AMH800	0	0	0	12%
AMH850	0	0		
Total	102,362	100	100	–

Source: Calculated based on data from National Seed Production and Distribution committee (only centrally distributed seed quantity) and figures from suitability maps.

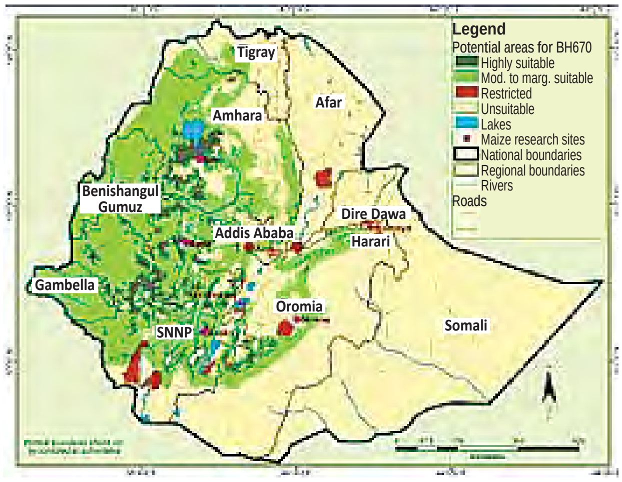
Table 3. Highly suitable areas for hybrid maize varieties by region (in ha).

Region	BH660	BH670	BH540	BH543	AMH800	AMH850
Tigray	61,872	47,072	179,356	179,356	16,268	14,868
Afar	796	256	4,424	4,424	0	0
Amhara	1,279,380	1,620,340	1,558,324	1,558,324	1,256,360	1,390,656
Benishangul Gumuz	163,508	134,448	1,421,408	1,421,408	40,316	45,660
Oromia	3,248,004	3,040,324	4,585,652	4,585,652	2,684,308	2,918,648
Somali	0	0	0	0	0	0
Dire Dawa	0	0	0	0	0	0
Harari	0	0	0	0	0	0
Addis Ababa	0	0	0	0	100	120
SNNP	1,730,872	1,810,124	2,087,820	2,087,820	1,446,064	1,519,124
Gambella	5,168	4,384	38,668	38,668	6,724	6,456
Total area	6,489,600	6,656,948	9,875,652	9,875,652	5,450,140	5,895,532

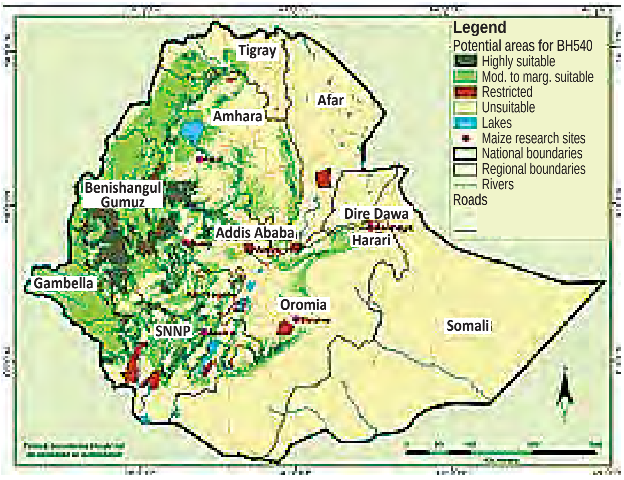
SNNP = Southern Nations, Nationalities, and Peoples (United Nations)



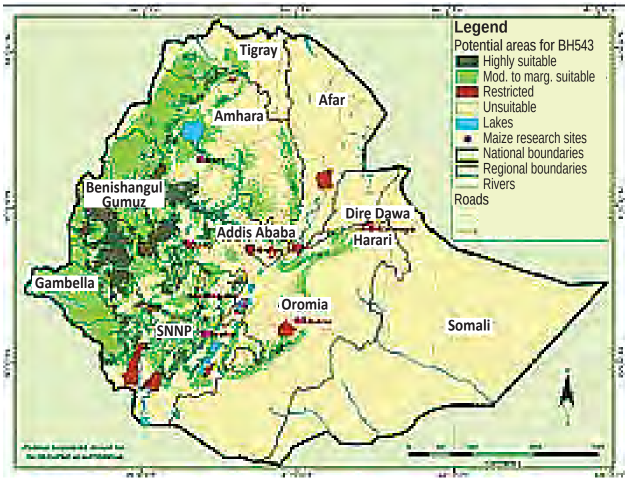
BH660



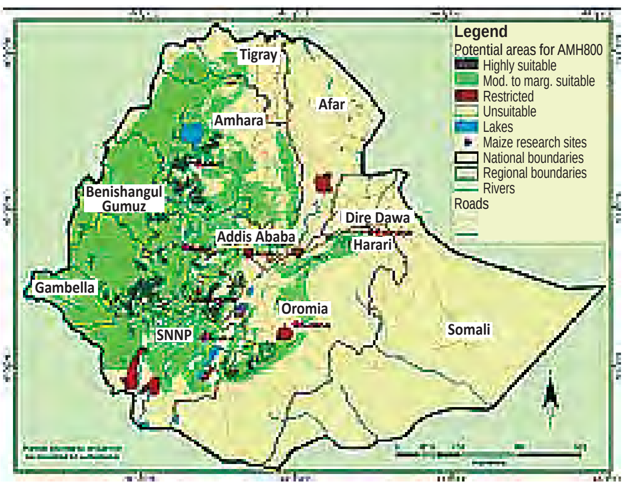
BH670



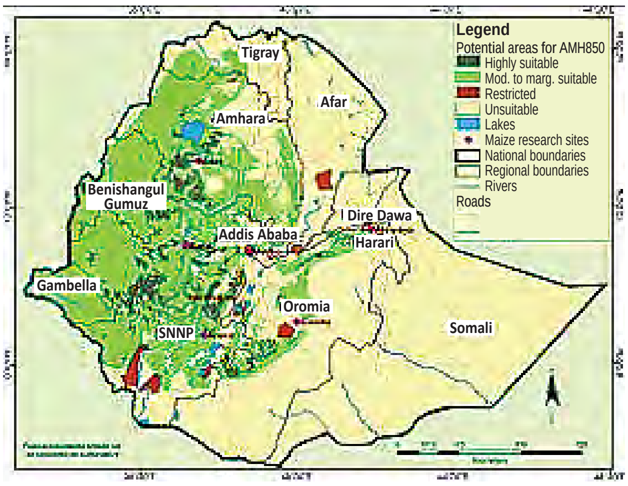
BH540



BH543



AMH800



AMH850

Figure 2. Distribution of potential areas for hybrid maize by variety.

Conclusions and Recommendations

The GIS based assessment of the suitability for popular maize hybrids show that there is clear distributional difference among the BH6, BH5 and AMH series but similarity within each series. This implies the need for better targeting in the production and distribution of maize hybrid seeds produced in the country. The current situation in the production of the seeds of maize hybrids shows the focus on hybrids for intermediate agro-ecologies with limited emphasis on the highland agro-ecology. This is commonly associated with poor seed demand assessment, and limited demonstration, popularization and demand creation for the available maize hybrids. Therefore, it will be important to (i) strengthen the seed demand assessment methods, (ii) promote the demonstration and popularization of the maize hybrids in their respective potential areas to create demand, and (iii) align all seed producers in targeting the production of the seeds of maize hybrids for respective agro-ecologies.

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The Potential Impacts of Climate Change–Maize Farming System Complex in Ethiopia: Towards Retrofitting Adaptation and Mitigation Options

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Introduction

A decrease in food supply caused by a variable and changing climate is one reason for the current skyrocketing food prices at a global scale (Lobell *et al.,* 2011). The term climate change here is best described by a rising-falling temperature following the trend in atmospheric CO_2 concentration and a highly variable precipitation, as well as an increase in frequency of extreme events (drought, flood, frost and resurgence of new pests). Regardless of where it occurs, this change is recognized as a major threat to food crop production worldwide, but nowhere more acutely than in poor countries (Mohmoud, 2008).

For Ethiopia, results from different global climate models (GCMs) reveal an increasing rainfall trend in the next century, despite the fact that the models could not fully capture local conditions, as rainfall is a conditional element, *viz*; it is modified rather by local factors; indeed, rendering the overall projected rainfall trend to have a lower confidence limit. On the other hand, temperature is increasing with a high degree of confidence: by 0.28°C per decade *viz.*, about 2.8°C at the end of this century (McSweeney *et al.,* 2008); and this is best defined by the increasing atmospheric CO_2. The existing knowledge on plant physiology confirms that CO_2 itself is the precursor for carbon fixation by the process of photosynthesis, but higher than optimal CO_2 concentration may certainly suppress this, with the situation getting more complicated when this is coupled with frequent drought in an area, that in turn causes a multiplier effect i.e., incidences and severity of biotic stresses, including resurgence of new pests. Understanding how climate change affects yield of the staple food crops is thus an issue of both scientific and societal debate.

Maize, a tropical crop on which millions depend for their livelihoods, is among those crops responsive to the expected change in climate; under both drought and non-drought conditions (Lobell *et al.,* 2011). The maize plant, being an efficient carbon user (C_4 plant), grows better at higher CO_2 levels because of its stomata structures that lie on the underside of leaves, consisting of guard cells surrounding the tiny pores on leaves and providing an advantage. The pore allows gases (CO_2, water vapor and O_2) to move into and out of the leaf; while pore diameter is controlled by the guard cells. When CO_2 levels are higher than optimal, the pores need to be open less wide, consequently they lose less water for a given amount of CO_2 taken up (Lobell *et al.,* 2011). It is essential that with the anticipated likelihood of maize production in the face of climate change in the future to re-position the research approach, especially with respect to the increasing heat load and soil water deficits, by tailoring maize related development efforts to climatic conditions with a clear understanding of the local socio-economic drivers (poverty, markets, local institutions, etc). This needs not only innovative thinking or retrofitting of those technologies and practices for a changing climate, but also a better knowledge and understanding of what should be the future maize research direction in Ethiopia.

Despite the challenges in climate risks, presently the maize research program in Ethiopia mainly depends on multi-location field trials in its variety development–demonstration–release continuum, while the application of crop-weather modeling that could provide large solutions, particularly in narrowing the knowledge gaps, has received minor attention. Linked to crop-weather modeling, those limited simulations done to date also suffer from the lack of data on potentially relevant cultivar characteristics, genetic coefficients, detailed soil properties and climate datasets. Statistical approaches are also limited by the quantity and quality of data used (Lobell and Burke, 2010); for instance, the lack of long-term records on grain yield and biomass data for the improved maize cultivars at a given experimental site has resulted in large uncertainties in impact modeling of the current and future climate change on maize farming. This may lock maize research dynamics into conventional approaches.

More challenging and difficult to address, are age old and poor maize farming practices that also enhance greenhouse gas (GHG) emissions, including but not limited to CO_2, methane (CH_4) and nitrous oxide (N_2O) that are powerful in trapping the outgoing infrared radiation. Among many others, the un-replaced deforestation normally results in a removal of the carbon stock. Ploughing steep slopes to grow crops in response to the declining per capita land availability also enhances soil erosion, thereby reducing 'soil carbon stock'. Further, maize stalks are composed of large quantities of carbon and nitrogen, thus the removal of crop residues from the farm for a variety of reasons (feeding animal or burning as fuel wood) also directly contributes to an emission of as much a quantity of CO_2 or its equivalent. Similarly, the inappropriate application technique of nitrogen containing fertilizers; including the synthetic ones, manure and incorporation of crop residues also reduce maize carbon-nitrogen use efficiency.

Currently, there is an increase in the awareness on reducing the impact of agricultural practices on global warming and climate change through 'the lower emitting techniques' which the Ethiopian government has categorically adopted in its national development strategy known as 'Climate Resilient Green Growth Economy' (CRGE) initiative that will continue through 2030. This initiative, the first of its kind in Africa, would draw on two diametrically opposite strategies i.e., one that reduces emission of the GHGs on one hand and increases productivity on the other, termed a win-win situation. This becomes highly relevant if the maize research and development effort is framed in this initiative. Assuming the international community can raise finance for the carbon captured through such 'sink farming', this must be a new asset class for the future maize-based research and development orientations as well. What is most concerning then is 'how knowledge on global climate (both acquired and tacit) could be brought into the local climate and maize farming perspective'.

It is against this background of climate-maize farming complex that it was found appealing to analyze and map future climate change, Ethiopia's degree of vulnerability to and impact of the changing climate, and followed by identification of maize-based adaptation-mitigation options. The paper also emphasizes how maize research could be aligned along the climate risk management orientation, compared to the current average oriented courses. In fact, those adaptation options in point may not be completely new to our maize researchers, and above all to the farmers. Historically, Ethiopian farmers have been reducing various climate risk profiles by adjusting the mix of crops as well as in use of indigenous tillage practices, in which the Konso in Southern Region and the Harla civilization (east Haraghie) have been marked for advanced soil water conservation practices over the last 500 years. Likewise, the use of organic manure, crop rotation and short fallow practices of Kindo Kosha and indigenous irrigation system of Amaro special *woreda* in southern Ethiopia could be shining examples. Scientifically too, our maize breeders have been successful enough in developing a number of maize varieties tolerant to drought, cold, diseases and insect pests that befit the contemporary climate situations, although this cannot by any means be an easy solution and breeding for these characteristics is not as simple as it sounds. On the other hand, little data is available on mitigation aspects due to maize farming practices.

This paper suggests relevant climate-maize farming practices via contextualizing complex challenges to the two globally recognized response strategies and also presents challenges and lessons learnt in research and development that are key to mainstreaming climate information into the background of maize research.

Materials And Methods

Firstly, maps of the projected change in precipitation and temperatures for Ethiopia until 2050 were adapted from the recent rigorous analytical output of Jury (unpublished) that was developed using the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (AR4) and running GFDL, GFD-0, CSM, PCM coupled models for rainfall and temperature. In the study, simple linear trend analysis has been employed, using monthly gridded data that has been averaged into annual blocks of grids. Year-to-year fluctuations are embedded in the time series. The same method is applied to all grid points or levels, which were then mapped, so that trends are shaded differently.

In sequence, two nationally strategic maize experimental sites were chosen; the first site is Bako, center of excellence for maize research at a national level, while the second action site, Melkasa, represents dryland farming zones. For those sites, ex-ante impact analyses of the projected precipitation, warming (temperature) and growing degree days (GDD) on maize production were assessed. Here GDD is a unit that reflects both the amount and duration of heat experienced by the plant in a cumulative way from planting through to physiological maturity. GDD is calculated by taking the average of the daily maximum (T_{max}) and minimum temperatures (T_{min}) compared to a base temperature, T_{base} (Equation 1). The base temperature is one below which plant growth is zero. For maize, 8^oC is taken as the base.

$$GDD = \sum ((T_{max} + T_{min})/2 - T_{base}) \qquad \text{Equation 1}$$

Prior to impact analyses, the selected areas were characterized for the important climate variables, including rainfall (onset date, end date, duration and seasonal precipitation total), temperature and GDD based on historical data on record. For season rainfall onset date, the criteria was the occurrence of 20 mm of rainfall running over 3 consecutive days and not followed by consecutive dry spells of no longer than 10 days within a month from planting. For rainfall end date, we have chosen the criteria of soil water balance near to zero.

In sequence, the global climate information was downscaled to the selected study sites to understand if the global information could reflect the impact at localized level, and based on which future daily climate data was generated until 2030 following the validation using past records. Subsequently, the generated data was submitted to the Crop Environment Resource Synthesis (CERES)-Maize routine in Decision Support System for Agro- technology Transfer (DSSAT) (Tsuji *et al.,* 1994) software in order to simulate the potential of future maize productivity until 2030. The process based CERES model simulates crop responses (water balance, phenology, and growth throughout the season) on a daily basis to the key indicators of climate (daily solar radiation, maximum and minimum temperature, and precipitation), soils and management (cultivar choice, planting date, plant population, row spacing, and sowing depth).

For Bako, the 160 days growth cycle cultivar-BH660 was used for yield simulation modeling, while for Melkasa, the 90 days short growth cycle, Melkasa1, which is being widely grown under soil water deficient conditions was chosen. The 'genetic coefficient' of the respective cultivars was derived from the existing agronomic and climatic data. The CERES-Maize model was validated using on-station experimental maize data for the period 1997–2007 for BH660 and 2000–2007 for Melkasa1. To examine if GDD could be a principal component in maize yield prediction, a regression analysis was also performed for the historical yields and the future scenario. The relationship between GDD during the growing season and grain yield of the identified maize cultivars was also analyzed for the two maize cultivars in point.

To master GHG emission through maize farming, first, emissions from crop residue incorporation were estimated based on IPCC methodology and the Central Statistical Agency (CSA) data on crop mix, while the synthetic fertilizer use for maize during 2010–2015 was projected based on GTP targets. The fertilizer usage growth through 2030 was estimated based on the World Bank 2015 fertilizer application estimate for countries with similar potential. Likewise, emissions from manure applied to land planted to maize were projected based on IPCC methodology and CSA livestock population data. A conversion factor of 296 was used in converting a unit of N_2O to a unit of CO_2 that was reported in million tons. For further details refer to Table 1 below.

Table 1. Emission drivers and conversion factor of CO_2 in maize farming.

Source	Type of greenhouse gas (GHG)	Conversion factor (kg N_2O / tons crop) to CO_2 equivalent
Synthetic fertilizer (DAP and urea)	N_2O	0.0009
Manure application	N_2O	0.0080
Crop residue incorporation	N_2O	0.0003

Source: Adapted from the draft CRGE document (2011)

Results and Discussion

The vulnerability analyses of Jury (unpublished) using the GCMs outputs of GFDL2 (Fig. 1a) and GFDL0 (Fig. 1b) show that, grossly, Ethiopian rainfall will get wetter in the next century with different locations responding differently. There will be a drying trend over the south western highlands which will be greatest over the River Baro catchment. The blue shades refer to a declining trend of 0.4 mm in every year. While the rate of change is not linear for the remaining locations, except some parts of the southern and northern tip of Ethiopia, on which rainfall will increase 0.2 mm y^{-1}.

The impact would most likely be pronounced in dry land areas, where more than 46% is already affected. Supportive to this finding, most GCM outputs have reached at least a consensus that Ethiopian rainfall will get wetter, but with low confidence. Further, the rate of warming is high in the lowlands, and less in the highlands. The diurnal range is larger in northeastern with drying trends. Red shades in Fig. 2 and Fig. 3 show an increasing trend of 0.03°C y^{-1} which implies that during the years 1964–2008 there was a 1.86°C increment of temperature (Figs. 2 and 3). Fig. 3 depicts a steep temperature increase with the projection into 2100.

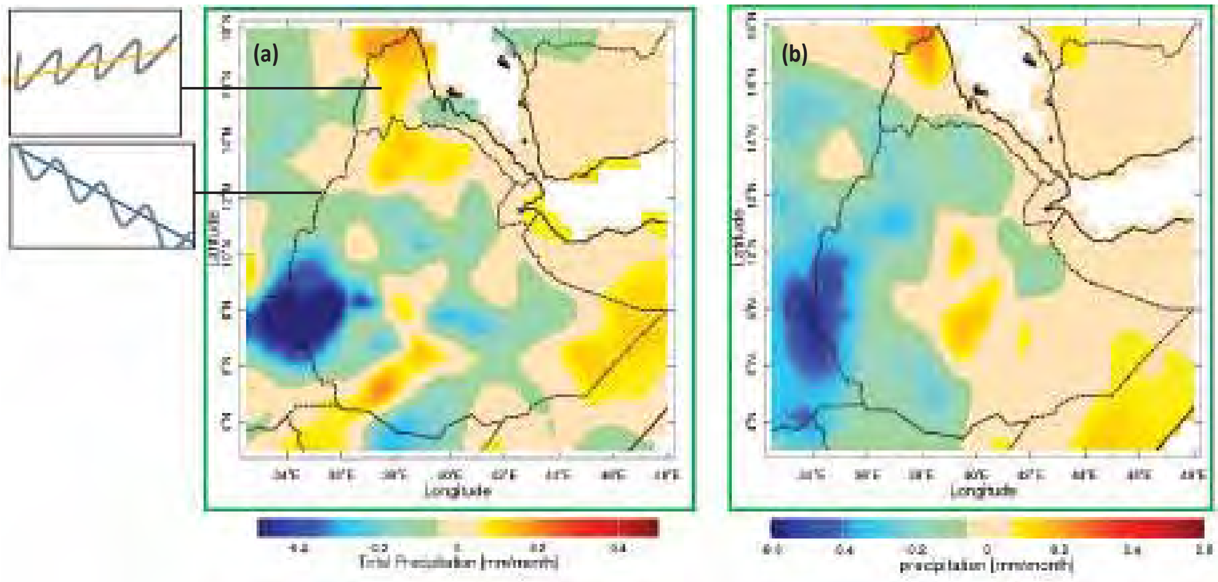

Figure 1. Past linear rate of change in interpolated observed data (1946–2008), for (a, left) GFDL2 rain and (b, right) GFDL0 rain.

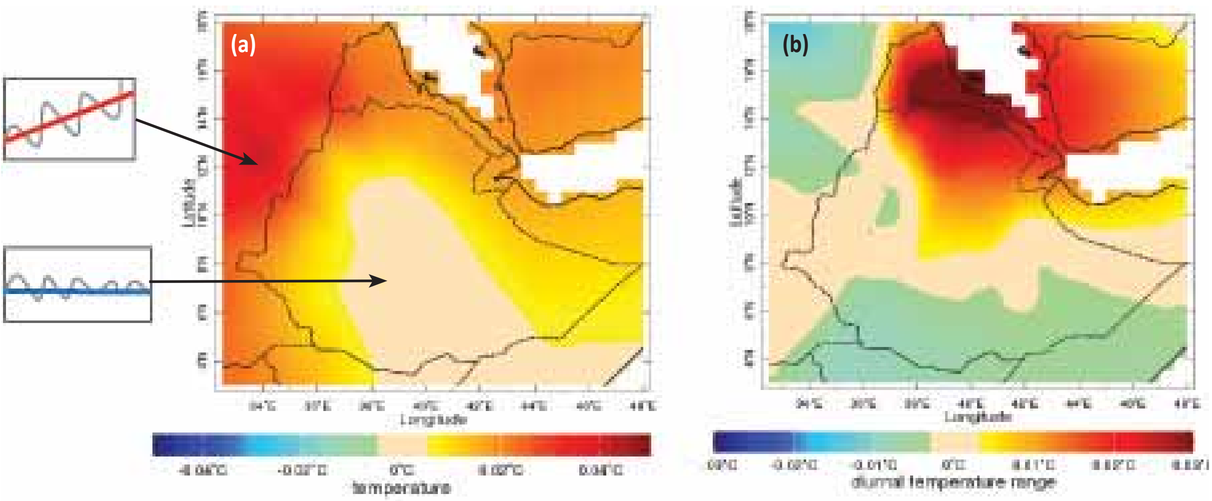

Figure 2. Projected climate change outputs of (a, left) GFDL and (b, right) GFDL0 of Ethiopia for the period 2011 to 2050.

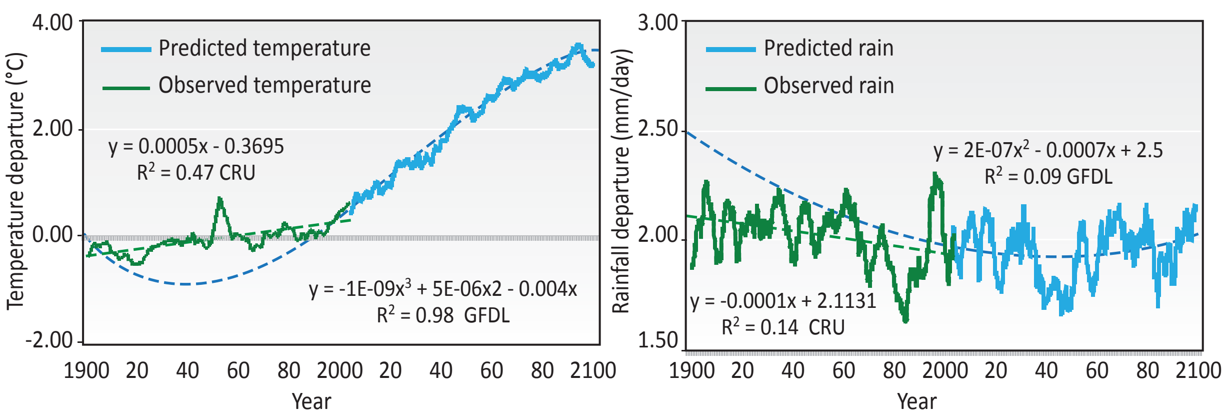

Figure 3. Ethiopian temperature change using AR4 A1B scenario.

Climatic Characterization of Maize Experimental Sites

Figs. 4a, b and c provide a range of the current climate contingencies around Bako. A note from Fig. 4a shows an average main season (*Kiremt*) rainfall onset date to be on the 121st day of the year (DOY), or 30 April, with the rainy season ending on DOY 282, or October 8. Accordingly, Bako is characterized to experience a median 158 day growing period, with a median seasonal rainfall total of 1,240 mm, and with 95% confidence limits for receiving more than 964 mm in 3 out of 4 years. The result confirms that Bako can afford maize cultivars with a maturity period around 5.5 months.

Fig. 4b depicts temperature minima and maxima for Bako, of 15.3 and 26.5°C during the growing season. From the work of Lobell *et al.* (2011) regarding the cardinal temperature for maize (8, 25 and 30°C), the average of 21°C at Bako provides the existence of room for enhancing maize production under rising temperature. The rest of the temperature percentiles could also be noted from Fig. 4b; for instance 27.2°C occurs in three out of four years, while 15.7°C is the minimum temperature in three out of four years. Fig. 4c, on the other hand reveals the accumulation of mean GDD of 2,254 units during the entire maize growth period, with the 75th percentile (three out of four years) being 1,875, and a maximum value of 3,351 units in the recorded climate history at Bako.

Fig. 5A reveals the prevailing rainfall features at the Melkasa site, including the onset date, end of season, duration and seasonal rainfall total (mm). The median meher rainfall onset date turns on DOY 178, or June 26, while the end of the season is on DOY 273 (end of September). Accordingly, the LGP for Melkasa is 95 days with a season median rainfall total of 503 mm,

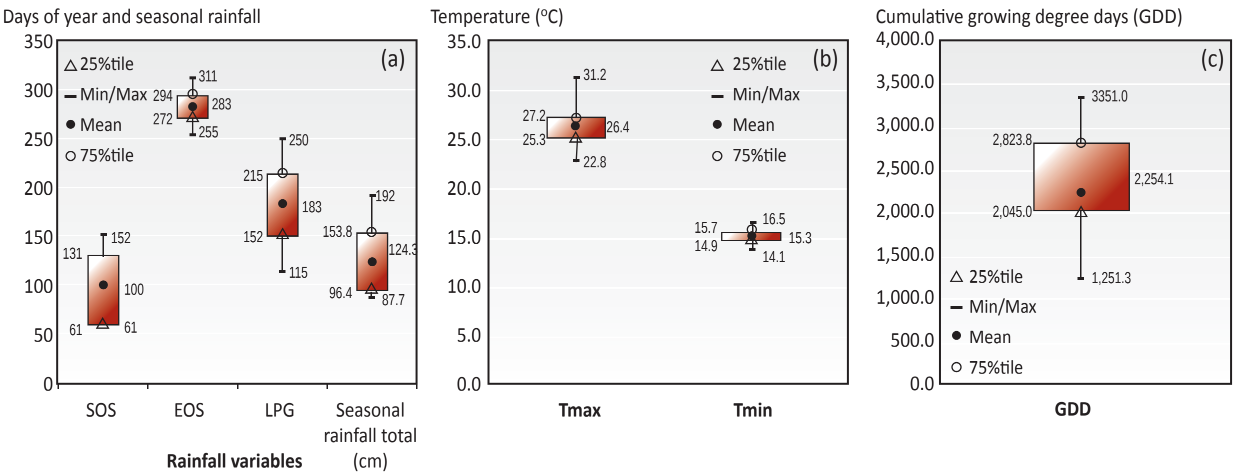

Figure 4. Descriptive statistics of (a, left) rainfall pattern at Bako Research Center, (b, center) average temperature, and (c, right) cumulative growing degree days/GDD.

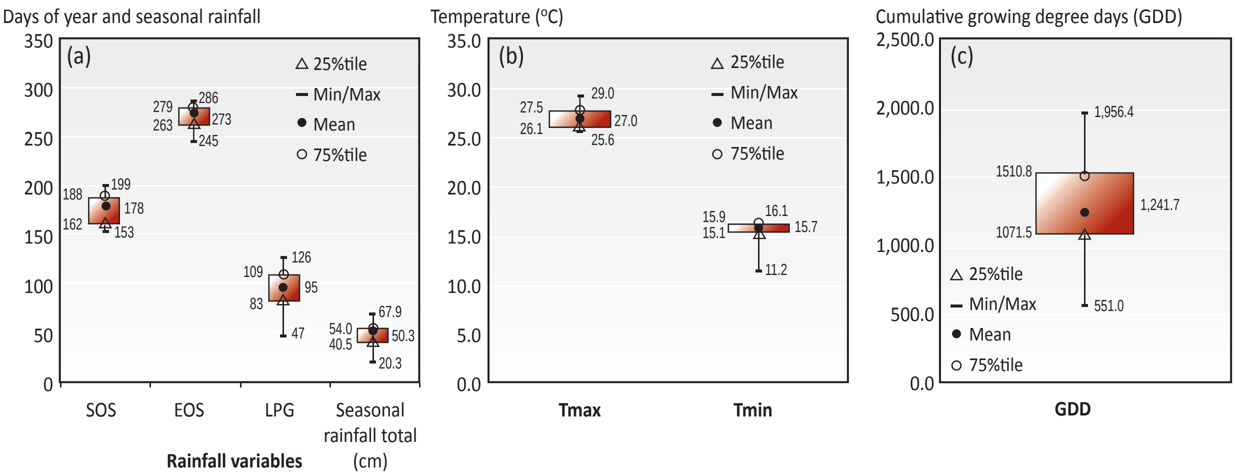

Figure 5. Descriptive statistics of (a, left) historical rainfall pattern at Melkasa Agricultral Research Center, (b, center) temperature maxima and minima, and (c, right) cumulative GDD.

and 540 mm is expected once in three out of four years. Fig. 5b describes the prevailing temperature maximum and minimum for Melkasa. The maximum during the growing season is 27.0°C, with the minimum of 15.7°C. From Fig. 5c, the mean available GDD is 1,241.7 units with the 75th percentile of 1,510.8 units. A more difficult question may arise as to whether the seasonal rainfall total of 500 mm range at Melkasa is considered any lower. This should be an irony in the national maize research, particularly when compared to the situation in other dry land countries. For instance, Australia receives 420 mm of annual rains, while Israel experiences in the order of 250 mm of annual rain and yet both countries realize high yields.

Future climates of the study sites were also characterized in terms of temperature and rainfall patterns. The result revealed that rainfall amount will increase for Melkasa at the rate of 2.2 mm per year, while it will decline in the case of Bako (Fig. 6) at the rate of 8.3 mm per annum; although the result is within a low confidence limit. Furthermore, the pattern of minimum and maximum temperature shows an increasing trend for both Melkasa and Bako; with the magnitude being greater for Bako, compared to that of Melkasa (Fig. 7).

Potential impacts of climate change on maize farming at strategic experimental sites

The net effect of atmospheric warming on yields was computed using the temperature index such as GDD. The relationship between the accumulated GDD along the growing season and grain yield of Melkasa1 revealed good pattern correlation *viz*; a change in grain yield also tracks the change in GDD curve; except for years 2003 and 2004 (Fig. 8). Closer scrutiny of rainfall data from the 2003 cropping season reflects a lateness in onset with extended intra-season dry spells and the corresponding higher daily temperature, which must have aggravated the soil water deficit. The corresponding higher GDD must have also enhanced the standing maize development, resulting in early maturation and therefore reduced grain yield. This result is in agreement with research output by Rosenzweig and Hillel (1998) and Chipanshi

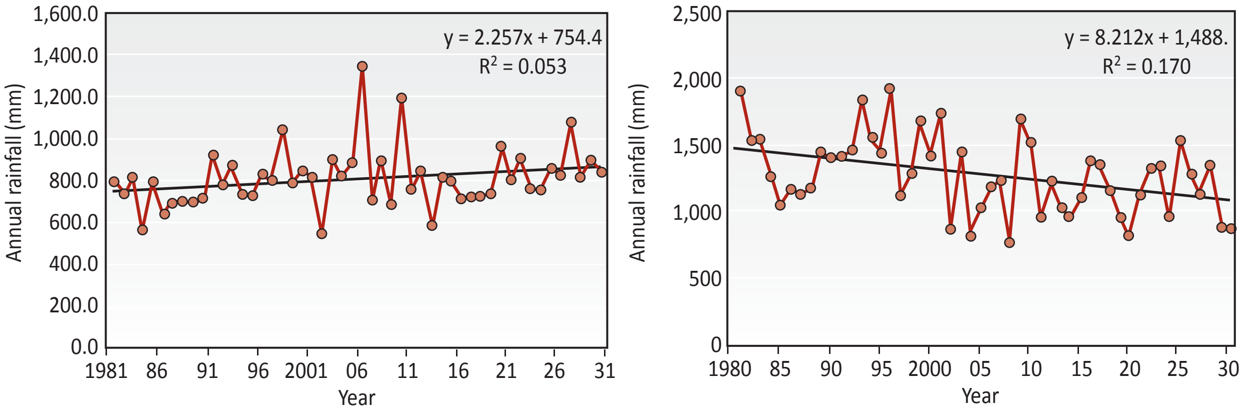

Figure 6. Trends in observed and projected annual rainfall for the Melkasa (left) and Bako (right) maize trial sites.

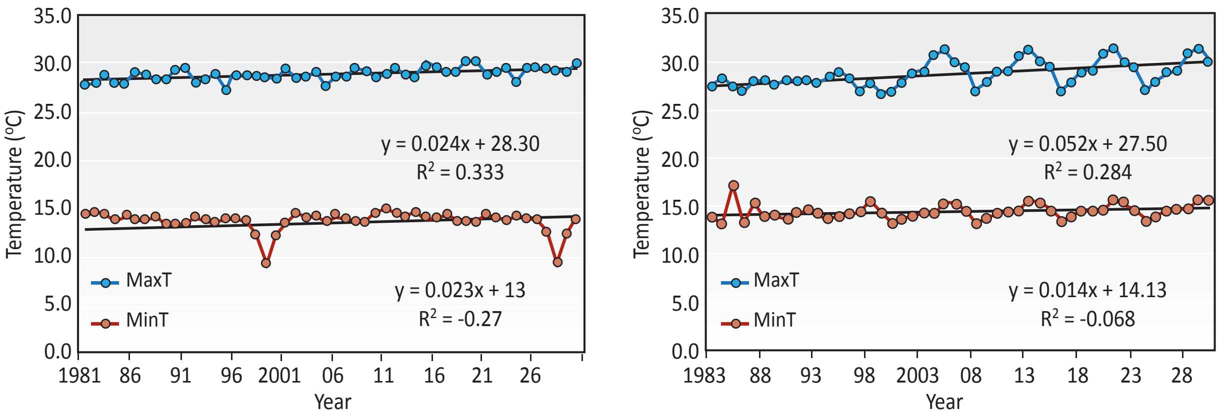

Figure 7. Trends in observed and projected minimum and maximum temperature for the Melkasa (left) and Bako (right) maize trial sites.

et al. (2003), in that when daily maximum temperature exceeded 30°C during the growing season, grain yield of maize declined. In the 2004 cropping season, the rainfall was good in terms of amount and distribution; thus the response of maize yield to GDD under a relatively higher moisture condition is higher, showing how yield response to GDD varies with the level of soil water availability.

At Bako, longer LGP and high seasonal rainfall total, as well as GDD, are expected, compared to that of Melkasa. The relationship between GDD and grain yield of maize (BH660) under the Bako climate shows a similar trend; except for the 2002 cropping season (Fig. 8). During the 2002 cropping season, a relatively higher temperature was experienced that contributed to the faster crop growth and development and earlier maturation, thus depressing the yield. Literature reviewed from the detailed works of Lobell *et al.* (2011) indicates growing maize below 23°C in average growing season tends to be responsive or gain from warming, owing to the positive effects of GDD, whereas yields of maize grown in areas above this baseline temperature tend to decline with warming. Similarly, sites above 25°C in average temperature decline quite rapidly, albeit a considerable uncertainty. Under drought conditions, even the coolest areas are harmed by 1°C warming, with losses exceeding 40% at the hottest sites. Again, this emphasizes the importance of moisture in the ability of maize to cope with heat. For Bako, the amount of rainfall available per growing season will be reduced due to climate change through 2030 (Fig. 9). This will also result in a reduction of yield at the rate of 65 kg ha^{-1}, while for Melkasa there would be an increase, despite the high uncertainty associated with both datasets. The dataset used here could, however, afford the potentially important role of variety switching as an adaptive response to climate change. Table 2 summarizes some of those anticipated best adaptation options.

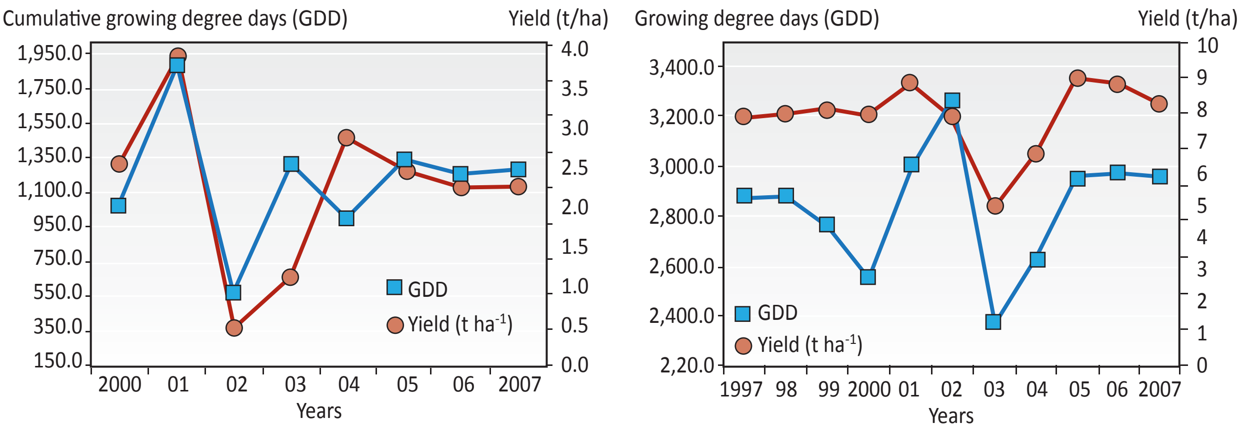

Figure 8. Pattern correlation between observed grain yield of Melkasa1 and GDD at Melkasa (left) and grain yield of BH660 and GDD pattern at Bako (right).

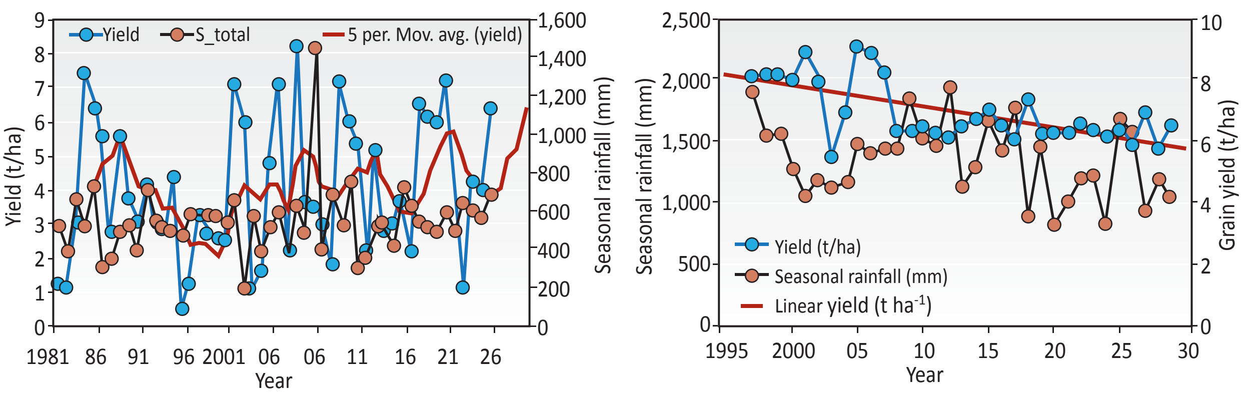

Figure. 9 Projected grain yield and seasonal rainfall pattern at Melkasa (left) and Bako (right).

Table 2. Farm level adaptation responses in maize to the highly likely climate change scenarios in Ethiopia.

Climate change scenarios	Most likely challenges/impacts	Adaptation options
Regions known for maize production run out of the system due to lack of rainfall (<250 mm)	• Crops' water requirement cannot be met at any growth stage and therefore maize production under rain-fed farming is impossible	• Total irrigation • Specialization
Irreversible shift in rain onset date from early to late	• Planting window of long cycle maize cultivars narrowed • High yielding long cycle maize cultivars cannot be grown any longer	• Modifying maize growth cycle cultivars befitting the modified rain season (medium or short duration cultivars)
Early season cessation	• Shortened length of growing period implies shortened grain filling period and shriveled grain	• Water harvesting for supplemental irrigation and increased water productivity (more yield per drop of water), providing better conditions for plants to grow • Weather index based insurance scheme (transfer one's risk to the third party)
Soil water deficit, evaporative demand exceeds rainfall amounts	• Maize production is possible, but rainfall insufficient to meet crop water requirement	• Water harvesting for supplemental irrigation at critical growth stages • Weather index based insurance scheme (partly, package) • Increasing water productivity (grain yield mm^{-1}) through cultivar choice and improved soil water management practices
Declining seasonal rainfall amount	• Maize production is possible, but rainfall insufficient to meet crop water requirement	• Water harvesting for supplemental irrigation at critical growth stages • Increasing water productivity (grain yield mm^{-1}) through cultivar choice and improved soil water management practices
Shrink in size of short season (*Belg*) rainfall areas	• Production areas in which short season (*Belg*) and main season (*Kiremt*) rains used to be merged with long cycle maize cultivars would be impossible	• Switch to the short cycle maize cultivars
Unpredictable rains due to increased variability in rain onset date and extremes	• Difficult to adopt fixed agronomic recommendations (date of sowing, cultivars, planting density and fertilizers)	• Use seasonal rainfall forecast information from the forecast communities for early warning and informed decisions at farm level • Weather index based insurance transaction to manage risk
Erratic distribution, extended dry spells (once the season sets in)	• Reduced maize yield or total crop failure due to shortage of moisture at critical growth stages	• Modifying maize growth cycle to ensure that plants experience sufficient moisture during the critical stages. • Blend a suite of maize varieties (early–late maturing), so that the harvest is less vulnerable to stress at critical periods
Torrential storms over a short time (days)	• Rainfall exceeds infiltration capacity of the soil, reduced stand establishment, slow growth rate	• Safe disposal of excess water (drainage), harvesting excess water to use at times of deficit
Heat load	• Premature switchover from vegetative to reproductive stage (required heat unit met earlier than usual) • Resurgence of new pests and pathogens	• Shift the temperature optima for crop growth through breeding • Varieties with roots that can withstand attack by soil-borne pests and diseases • Develop heat tolerant cultivars

Impact of maize farming practices on climate change

Viewing through the opposite prism, maize farming practices themselves contribute to climate change through the differential emissions of GHGs from the practices. Fig. 10 provides an estimate of CO_2 equivalent GHG emissions from three main drivers (manure, incorporation of crop residue and use of synthetic fertilizers) under a business as usual development scenario for two benchmark periods (2010 and 2030). From Fig. 10, manure application either from composting or direct application is estimated to emit 0.03 million tons of CO_2 equivalent GHGs in 2010, while the same estimation would yield around 0.2 million in year 2030. The N_2O, as driven by the increased interest of government policies in promoting the use of manure in organic fertilization is 296 times more absorptive of the infrared rays than CO_2. For the direct application of crop residues (either *in situ* retention or *ex situ*), the estimated emission of GHGs has reached 0.18 million in 2010 and 0.5 million tons by 2030. N_2O is yet considered the source for the estimated emission, following the 2011–2015 GTP of the country. On the other hand, an estimated quantum of 0.45 million tons of CO_2 equivalent GHGs would be emitted from maize farming in 2010, with expectations reaching 1.2 million tons by 2030, an emission yet driven by the increased use of synthetic fertilizers, as planned by the GTP.

The argument from maize research may suggest that the 'maize plant releases as much CO_2 as it has absorbed through its growth phases, which implies neutrality in effect, indeed where the danger lies is unclear'. In fact the danger lies in the fact that atmospheric CO_2 concentration is increasing beyond the tipping point, a range beyond which maize plants can no longer absorb; thus resulting in imbalance. Recognizing that maize is a C_4 plant, where the four carbon product is first released in the photosynthetic process, the relevant question of common interest to both parties may then take the form: may maize (C_4 plants) be disadvantaged under the future climate change of Ethiopia and can the national maize research afford to address this complex challenge?

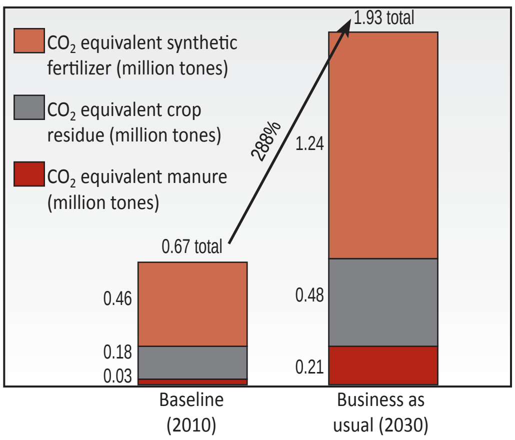

Figure 10. Estimated CO_2 equivalent emission from three sources in maize farming under business as usual scenario until 2030 in Ethiopia.

Albeit indicator data are scant to fully substantiate, the following bullets suggest the strategies to be adapted under the theme 'enhancing lower emitting techniques or increasing maize sink capacity' with the concomitant increased maize productivity and production.

- Breeding for maize cultivars known in use of excess carbon and nitrogen use efficiency.
- Use of slow release nitrogen fertilizers (replacing the existing nitrogen fertilizers with the optimally blended ones and ones with low conversion factors), as well as application techniques that ensure slow N-release (ex; urea granulated). Currently, the MoA has started piloting the potential benefits of alternate synthetic fertilizers, relative to urea and DAP.
- Promote uses of organic fertilizers (green manure, vermi/compost, bio-gas-slurry, bio-fertilizers/ rhizobia) in maize farming systems.
- Adjust fertilizer rates to maize crop needs (e.g., soil test and targeted yield analyses based applications).
- Integrated maize–legume cropping system, including relay farming.
- Promotion of conservation agriculture (CA), including the maize-forestry system. The CA principle affords to follow the principles of minimum disturbance of the soil, incorporation of at least a third of the aftermath on the farmland and rotation, in view of the sustainable maize production and ecosystem benefits. CA also affords in this respect, the use of integrated fertilizer management, while integrated fodder maize. Agro-forestry system also reduces the pressure on crop residue removal from farmland.

Conclusion and Recommendations

The existing rich body of knowledge and our analytical results show that climate change, as largely manifested through warming and increased variability in precipitation is already a reality in Ethiopia. The study result shows that impacts of a rising temperature on maize production in Ethiopia remain uncertain and there could be a risk of significant yield losses. Thus, the impact of climate change on maize productivity is highly likely. It was also learnt that the maize farming practice itself is impacting on the climate. The key to learn then: the future time would turn hardest to our maize researchers in taking advantage of the increasing global warming or stabilizing yields under severe conditions.

It is suggested that maize planted in a future Ethiopia that is characterized by a drier and hotter climate will need to be able to withstand the joint stress imposed by heat and drought and practices in different adaptation and mitigation options that simultaneously increase maize productivity and reduce the adverse impacts of the dynamics in climate change must be captured. This in other words implies that, time is high, right and ripe for climate change adaptation and mitigation mainstreaming into the national research and development efforts.

We also learnt that there is nothing new in perspective about adaptation and mitigation response strategies as both of them are in practice, but it only needs repositioning of course with a new level of thinking and to build on them i.e., retro-fitting. Now maize breeders and physiologists have to consider how the variety will perform in an environment with higher levels of CO_2 and greater variability in temperature and water availability. Tomorrow's variety must be able to withstand conditions that are not only hotter or drier, but also more variable. Finally, understanding the issue and searching for possibilities and opportunities through maize-climate risk and impact modeling and establishing the balance with empirical confirmation is the best way forward under future climate changed Ethiopia. The business as usual approach can no longer be the way forward. Let heaven help us!

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Pest Risk Analysis for Maize Importation into Ethiopia: A Case of Eight Source Countries

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Introduction

The maize improvement program in Ethiopia utilizes a large amount of germplasm from external sources, and thus, over 34,000 maize seed samples were imported from different countries including Mexico, Kenya, Zimbabwe, Nigeria and Syria from 2001 to 2008. Presently, Ethiopia imports an average of 4,300 maize seed samples every year (unpublished data). Uganda, USA, South Africa and Burkina Faso were also among major sources in the past (Awgechew, 1993, 2002).

Quarantine precautions against inadvertent importation of pests during germplasm and technology exchange have been an important topic in the world for many years. Accordingly, periodic reviews of quarantine information were published on maize importation into Ethiopia (Awgechew, 1993, 2002) to increase awareness in the country. Plant quarantine guidelines for the national agricultural research system (NARS) were published by the Ethiopian Institute of Agricultural Research (EIAR) (Dereje, 2006) to support the risk management operations at the national level. During maize importation, regular inspection was carried out at Holetta Agricultural Research Center (HARC) of the EIAR for freedom from pests that include insects, pathogens and weed seeds. Reports indicated that until 1990 alone 45 maize shipments were destroyed by appropriate methods due to infestation with serious and risky pests (Merid *et al*., 2008). Additionally, in accordance with our inspection guidelines and procedures, about 12.6% of the maize materials imported into the country were cleaned, sorted or treated with appropriate seed treatment to safeguard the country from alien pests of quarantine concern.

Inspection procedures followed in the past were those recommended in previous reviews (Awgechew, 1993, 2002) and more recently, additional post-entry follow-ups were carried out in accordance to Dereje (2006). At present, however, importation of plant materials into a country necessitates a consideration of recent advances in regulatory sciences for sound biological, economic, social and policy decisions. Current trends in quarantine inspection and post-entry follow-ups for any plant commodity require guidelines and procedures outlined by the sanitary and phytosanitary (SPS) standards that conforms with the terms of the International Plant Protection Convention, rectified by Ethiopia. In order to be effective in this important regulatory pest management undertaking, this review attempts to provide a concerted approach for effecting pre- and post-entry regulatory measures for maize importation into Ethiopia based on pest risk analysis (PRA). Accordingly, this paper describes quarantine precautions in the import control scenarios and presents PRA based on pathway analysis for importing maize seed into Ethiopia from eight major source-countries including Mexico, USA, Burkina Faso, Nigeria, Uganda, Kenya, Zimbabwe and South Africa. It also provides protocols for inspection and detection, and phytosanitary measures for potentially risky pests to safeguard the country. Finally, it proposes a list of important considerations for the future.

Mechanism of Import Control

The mechanism of plant quarantine operates under five sets of guiding principles and procedures comprising embargoes, inspection and certification, disinfection, special permits, and unrestricted shipments. In order to be effective, both pre- and post-entry quarantine measures are very important and complementary. Pre-entry quarantine includes importing maize from pest-free areas, field inspection at the country of origin, and laboratory tests and seed treatment at the country of origin based on the results of PRA. Post-entry follow–up, however, includes closed quarantine, production of pest-free seeds, field inspection and cleaning, laboratory testing and seed treatment and disposal of risky samples. Since the scope of this paper is limited to experimental materials, embargoes and unrestricted shipments are not considered. As a result, importation of maize seed into Ethiopia (Table 1) so far considered the prior approval of import permits by the

Table 1. Maize planting materials imported into Ethiopia in the last 8 years.

Year	Number of samples	Origin
2001	5,697	Kenya, Mexico
2002	5,505	Kenya, Mexico, Nigeria, Zimbabwe
2003	5,295	Kenya, Mexico
2004	3,809	Kenya, Mexico
2005	2,245	Kenya, Mexico
2006	3,893	Kenya, Mexico, Syria
2007	2,582	Kenya, Mexico
2008	5,382	Kenya, Mexico

Source: Holetta Agricultural Research Center (unpublished data) regulatory body Ministry of Agriculture (MoA) and each imported consignment was accompanied by a world standard phytosanitary certificate from the source country based on inspections of competent experts. All prerequisites to be fulfilled in the certificate are specified in the import permit and hence samples should be treated accordingly during and after shipments. After verification and release of the consignments for post-entry follow-up by EIAR, all samples were subjected to a series of inspection and detection procedures, although still not adequate. Cleaning, sorting and disinfection were carried out to salvage safe germplasm materials whenever possible and unsafe ones were destroyed to avert risk.

Pest Risk Analysis (PRA)

In actual practice, on a worldwide scale, issues of inadvertent importation of potentially hazardous pests into new areas arise in relation to several dimensions that include biological, economic, political and social scopes (Kahn, 1979). These are factors determining the entry status of an item, in our case maize seed, and subsequent post-entry follow-up. When only one of these factors, especially the biological factor, is in use to determine the entry status of items, the activity ought to be based on PRA. PRA is a thoughtful process whereby the entry status of maize plant, plant products, cargo, baggage, mail, common carriers, etc. is based on calculated risk of inadvertently introducing hazardous pests/pathogens with the maize as transported by man (Kahn, 1979; Merid *et al*., 2008). Therefore, PRA is an indispensible process when importing maize seed into this country and hence is carried out for maize seed importation into Ethiopia from eight major source-countries using information from the CABI Plant Protection Compendium (CABI, 2007) and current information on pests and diseases of maize in Ethiopia (Dereje *et al*., 2008; Girma *et al*., 2008; Emana *et al*., 2008).

PRA has three phases including (i) initiation, (ii) risk assessment, and (iii) risk management. The initiation phase starts with the request of a client to import plant materials for planting. At this stage, plant quarantine specialists initiate PRA with some details described in the request form. If no specific pest species were a concern in this import request, a pathway analysis of PRA options was perceptibly followed and the pathway details considered in this paper are (i) country of origin, including Mexico, USA, Burkina Faso, Nigeria, Uganda, Kenya, Zimbabwe or South Africa, (ii) importing country is Ethiopia, (iii) crop is *Zea mays L.*, and (iv) commodity type is seed.

Risk assessment considers two areas of information that eventually determine the pest balance of the country. Pest balance, in this case, is the list of pests that are present in the country of origin minus the list of pests widely distributed in the importing country. From this, two pest categories including those potentially requiring phytosanitary measures and those pests excluded from the risk assessment are determined. This information enables us to differentiate pests of quarantine concern to the country (Table 2). Listing pests and determining the mode of transmission and dissemination from source to destination are important and a useful tool to decide import permissions or on the type and level of post-entry follow-ups. New pest records from all directions are essentially important for conducting a sound PRA. Pests recorded on the host plant, liable to be carried on the commodity and absent in the importing country are considered for phytosanitary measures (Table 2) while pests recorded and widely distributed in the importing country were excluded from risk assessment (Table 3). Currently *Puccinia polysora* (American corn rust) has been recorded in Ethiopia on maize as a major disease (Tewabech *et al*., 2002; Girma *et al*., 2008) and hence the pest list considered in CABI Plant Protection Compendium was modified for this PRA. Generally, the order of pests in PRA follows as (i) insect, (ii) fungus, (iii) bacteria, (iv) viruses, (v) nematodes, and (vi) weeds.

A total of 20 pests (including 14 arthropods, 3 fungi, 1 bacterium, 1 virus and 1 spiroplasma) are of quarantine concern when importing maize seed into Ethiopia from the eight major germplasm source-countries considered in this PRA (Table 2). The number and species of pests of quarantine concern for the country vary depending on country of origin—the highest being in Uganda consisting of 19 pests followed by USA (16 pests) and then Mexico (11 pests). The rest consists of only 1–4 pests of quarantine importance for Ethiopia. Risk elements considered for this analysis included climate–host interaction, host-range, dispersal potential (population dynamic and epidemiology), and possible economic and environmental impacts. Accordingly, detection protocols and phytosanitary measures are given for each pest or category in the following sections.

Protocols for Inspection and Detection

Maize seed inspection: Dry seed inspection is the primary step in seed study for pests and all samples pass through this process. Usually, visual or aided examination of dry seeds using magnifiers or binocular microscope provides adequate information on the presence of pest infestation or symptoms of seed infection from many pathogens. Some pathogens and internal infestation by arthropods, however, need special detection methods to confirm pest infestation. In this case, appropriate detection methods should be specified for each specific pest considering its requirements and conditions.

Detection of arthropods: Fourteen arthropod pests (Table 2, No. 1–14) are of quarantine concern for Ethiopia. Inspection, as described above, is just enough to confirm external infestation. Internal infestation, however, needs further detection methods that include dissection, incubation, staining or X-ray. For maize seeds, dissection and/or incubation methods could provide adequate information and are dependable methods, although time consuming. Specific conditions of the pest or group of pests determine the conditions of incubation.

Detection of fungi: Three fungi (*Cocliobolus, Fusarium* and *Mycosphaerella;* Table 2, No. 15–17) are of quarantine concern in imported maize seed to

Table 2. Pests of maize potentially requiring phytosanitary measures when imported into Ethiopia.

No.	Pest	Mexico	USA	Burkina Faso	Nigeria	Uganda	Kenya	Zimbabwe	South Africa
1	*Anaphothrips obscurus* (grass thrips)	x	x			x			
2	*Carpophilus* (dried-fruit beetles)	x	x		x	x	x		x
3	*Helicoverpa zea* (American cotton bollworm)	x	x			x			
4	*Lugus lineolaris* (tarnished plant bug)	x	x			x			
5	*Mythimna unipuncta* (rice armyworm)	x	x			x			
6	*Peridroma saucia* (pearly underwing both)	x	x			x			
7	*Phyllophaga* (white grubs)	x	x			x			x
8	*Spodoptera frugiperda* (fall armyworm)	x	x			x			
9	*Chaetocnema pulicaria* (corn flea beetle)		x			x			
10	*Glischrochilus quadrisignatus* (four-spotted sap beetle)		x			x			
11	*Ostrinia nubilalis* (European maize borer)		x			x			
12	*Papaipema nebris* (stalk borer)		x			x			
13	*Aceria tosichella* (wheat curl mite)		x			x			
14	*Sesamia nonagrioides* (Mediterranean corn stalk borer)				x		x		
15	*Cochliobolus heterostrophus* (southern leaf spot)	x		x	x	x	x	x	x
16	*Fusarium* spp. (seedborne fusaria)		x			x			
17	*Mycosphaerella zeae-maydis* (yellow leaf blight)		x			x	x		x
18	*Pantoea stewartii* (bacterial wilt of maize)	x				x			
19	*Spiroplasma kunkelii* (corn stunt spiroplasma)	x				x			
20	Maize chlorotic dwarf virus		x			x			
	Total number of pests for each country	11	16	1	3	19	4	1	4

Source: CABI Plant Protection Compendium, 2007; Emana *et al*., 2008; Girma *et al*., 2008.

Table 3. Pests excluded from the pest risk analysis conducted for maize seed importation into Ethiopia, 2009.

Pest	Mexico	USA	Burkina Faso	Nigeria	Uganda	Kenya	Zimbabwe	South Africa
Delia platura (bean seed fly)	x	x			x	x	x	x
Rhopalosiphum maidis (green corn aphid)	x	x		x	x	x	x	x
Glomerella graminicola (red stalk rot of cereals)	x	x	x	x	x	x	x	x
Puccinia sorghi (common rust of maize)	x	x		x	x	x		x
Setosphaeria turcica (maize leaf blight)	x	x	x	x	x	x	x	x
Sphacelotheca reiliana (head smut of maize)	x	x	x	x	x	x	x	x
Stenocarpella maydis (ear rot of maize)	x	x		x	x	x	x	x
Ustilago zeae (common smut of maize)	x	x		x	x	x	x	x
Puccinia polysora (American corn rust)	x	x		x	x	x	x	x
Cucumber mosaic virus (cucumber mosaic)	x	x		x	x	x	x	x
Maize dwarf mosaic virus (dwarf mosaic)	x	x	x	x	x	x	x	x
Sugarcane mosaic virus (mosaic of abaca)	x	x		x	x	x	x	x
Total number of pests for each country	12	12	4	11	12	12	11	12

Source: CABI Plant Protection Compendium, 2007; Emana *et al*., 2008; Girma *et al*., 2008.

Ethiopia. Blotter and agar plate methods could generate reliable data at a reasonable cost. The blotter method is rather easy and in the agar plate method, general media such as Potato Dextrose Agar, Malt Extract Agar or any seed extract enriched dextrose-agar and incubated at temperature between 20 and 25°C could serve the purpose.

***Detection of the bacterium*:** One bacterium (*Pantoea stewartii*) is of quarantine concern in maize seed imported into the country (Table 2, No. 18). Many workers (Vishunavat, 2007) recommended enzyme linked immunosorbent assay (ELISA) for detection of this bacterium. However, the agar plate method could generate data at a reasonable cost. Specifically, the medium should contain important nutritive substances and eventually be incubated at 25°C.

***Inspection and detection of viruses and spiroplasma*:** One virus (Maize chlorotic dwarf virus) and one spiroplasma (*Spiroplasma kunkelii*) are of quarantine concern in maize seed imported into Ethiopia (Table 2, No. 19–20). Inspection could not help much for this group of agents. Thus, detection methods including grow-out test in the greenhouse and field inspection with rigorous rouging for cleaning could help in reducing the risk of establishment in the country.

***Inspection of weed seeds and identification*:** Maize seed should be free of any weed seed to avoid their establishment in the country. Visual and/or aided inspection of dry seeds using magnifiers or binocular microscopes provide adequate information on presence of any weed seed, but identification of the weed species requires growing weed seed under well-protected situations in the greenhouse. Weed species of quarantine concern to Ethiopia should be handled with great care and responsibility.

Phytosanitary Measures Against Pests of Quarantine Concern

Phytosanitary measures include all risk management aspects that individuals and/or groups operate at different levels to safeguard the country from hazardous alien species. Therefore, the following points should be considered during the process of importation:

1. Specify seed treatment with effective insecticides against arthropods and effective fungicides against fungi of quarantine concern for Ethiopia in the import permit form and provide this information to your source before shipment.
2. Inspect consignments (samples and containers) for pest infestation during arrival at entry ports (land, sea or airport) and destroy infested parcels, bags and boxes by appropriate methods. The National Plant and Animal Health and Quality Inspection Service of the MoA, Ethiopia, is responsible for these measures and all must cooperate for the success of this important control measure.
3. After the release of consignments by the MoA, seed samples should be inspected thoroughly and suspected samples subjected to appropriate detection methods described earlier. Consider cleaning, sorting, physical treatment, chemical treatment, etc. of suspected samples to salvage clean and safe maize materials. A list of prohibited weed species and other articles is given in the Plant Quarantine Regulation of the Council of Ministers Article 4/1992, Ethiopia or in the plant Quarantine for NARS (Dereje, 2006). If salvaging through these methods does not seem to be feasible, then the samples should be destroyed together with containers using an incinerator.
4. All samples imported for research should usually pass through post-entry follow-ups depending on the situation (Dereje, 2006). Different measures and handling are specified for quarantine pests of maize in the following post-entry follow-ups section.

Post-Entry Follow-Ups

Receiving maize samples for post-entry follow-ups involves inspection and detection of pests of quarantine concern in maize seed. Samples are subjected to appropriate phytosanitary measures described above and post-entry measures described hereafter, depending on the specified conditions required. These measures and practices include:

***Field inspection and cleaning*:** Maize imported for research purposes is planted in the first season only at Ambo (for highland types), Bako (mid-altitude sub-humid), or Werer and Melkasa (low moisture stress areas) where field inspection and cleaning is done by crop protection specialists. At this stage, rigorous rouging and destruction of suspected pest, refuses or any strange plant in the nursery are important activities. Both viruses and the spiroplasma show conspicuous symptoms and hence are safely cleared during field inspection and cleaning.

***Growing–on test*:** Some samples might be very small and suspected for bacterial wilt of maize by *Pantoea stewartii*. ELISA was the only recommended detection method for this bacterium, however, some labs use the growing-on test. In this case, samples are tested in the greenhouse under controlled conditions where seeds from only healthy plants are released for planting in the next season.

Seedling symptom test: Some maize samples may be very small and suspected for the bacterial wilt of maize by *Pantoea stewartii* or the virus Maize Chlorotic dwarf virus and/or spiroplasma *Spiroplasma kunkelii* that are of quarantine concern to the country and hence such samples are tested in the laboratory and seedlings are observed for infection with only clean ones transplanted to give clean seed.

Grow under controlled conditions: Some maize samples might be very small and suspected for any number of serious pests including arthropods, fungi, bacteria, or viruses which are of quarantine concern to the country. These are tested in the lab/greenhouse/cold-frame/quarantine fields and then clean seeds are released for planting in the next season.

Future Considerations

- Importers of maize into Ethiopia need to strictly consider the information provided in this paper before, during and after arrival of maize samples for research.
- Listing of pests, especially pathogens causing maize diseases should follow scientific methods that eventually confirm their existence and depict their distribution in the country.
- All aspects of risk management (phytosanitary measures recommended) suggested in this paper should be implemented and post-entry quarantine should be considered an essential criterion for advancing imported maize into subsequent nursery stages.
- Plant protection specialists should be involved in the early growth stages of imported maize samples and subsequent follow-ups for at least two seasons of nursery management to reduce the risk of pest establishment.
- There should be adequate cooperation with National Quarantine System that provides guidance and authority to this important issue with shared responsibility to safeguard national agriculture and the environment.
- A network among scientists working in maize improvement and staff in the extension system in maize growing areas should be established to obtain timely pest assessment records and feedback on strange pest occurrences.

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Review of the Past Decade's (2001-2011) Research on Pre-Harvest Insect Pests of Maize in Ethiopia

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Introduction

In Ethiopia maize has been selected as one of the national commodity crops to satisfy the food self-sufficiency program of the country to feed the alarmingly increasing population. As compared to other cereals, maize is the highest in production and potential grain yield per unit area. However, the potential of this crop is not fully realized. Among the factors contributing to low grain yield is the damage inflicted by various insect pests. More than 40 species of insect pests have been recorded on maize in the field (Abraham *et al*., 1992), of these, only a few are of economic importance and have received research attention. Crop damage inflicted by *Lepidopterous* stem borers and termites is among the major maize production constraints contributing to low grain yield.

Four species of *Lepidopterous* stem borers have been recorded on maize in Ethiopia. These include *Busseola fusca*, *Chilo partellus*, *Sesamia calamistis* and *Sesamia nonagriods.* Of these *B. fusca* and *C. partellus* are by far the most important pests. *B. fusca* is the major insect pest of maize at high altitudes, high rainfall and cool areas, whereas *C. partellus* is the major pest in low altitudes, low rainfall and warm areas of the country (Emana *et al*., 2002). More recent studies, however, revealed that *C. partellus* has begun to expand its distribution into the cool mid and high elevation areas because of its competitive advantages over *B. fusca* (Emana *et al*., 2002). The complex biology of cereal stem borers, mainly the cryptic feeding nature at the damaging stage (larval stage) made their control difficult. To combat the complex species of stem borers involved in the damage of important cereal crops like maize, quite a large number of basic and applied studies have been conducted which include economic importance, distribution, species composition, biology, ecology and management. By doing so, several encouraging results were obtained which reduced grain yield losses below the economic threshholds.

Termites are also serious pests of agricultural crops, forest trees, and buildings in West Wollega, Ethiopia. A number of termite species are involved in the infestation. Over 300 samples of termites were collected and classified from eastern, western, and southern Ethiopia. They included 41 species belonging to 18 genera. Those associated with damage to crops belonged to the subfamily *Macrotermitinae*. They attack maize plants at all growth stages. Termites of the genus *Microtermes* are known to damage the root system of mature crops. *Macrotermes subhyalinus* damaged young maize plants (Barnett *et al*., 1987). Feeding damage to roots and stem bases frequently result in plant lodging and damage to cobs causing yield losses between 15% and 30% (Emana *et al*., 2008). Observed losses on seedlings varied with location (Emana *et al*., 2008). Damage to maize by termites was more serious when termite attack was severe enough to cause lodging or when attacks occurred on lodged plants. Insects such as the armyworm, chafer grub, grasshoppers, and maize aphids are also important although their occurrence is not regular. Although numerous pest species have been recorded on maize in the field, research activities have focused mainly on stalk borers and termites.

Previous research activities up to 2001 were reviewed and compiled during the First and Second National Maize Workshops (Abraham *et al*., 1992; Ferdu *et al*., 2001) and in a series of crop protection workshop (Adhanom and Abraham, 1985; Emana *et al*., 2008) proceedings. The objective of this review is, therefore, to compile maize research activities on stem borers and termites since 2001. Some research reports that were not included in the Second National Maize Workshop proceedings are also presented in order to accommodate effective stem borers and termite management options and to identify priorities for future intervention.

Survey of Natural Enemies of Stem Borers

Cotesia flavipes

C. flavipes is an endo-larval parasitoid of stem borers highly considered in the classical biological control of *C. partellus* in eastern and southern African countries. The parasitoid has never been released in Ethiopia. However, it was for the first time recorded by Emana *et al.* (2001, 2003a) in 1999 across the country. It was assumed that the parasitoid crossed over to the country from a release made in Somalia in 1997 by the International Centre of Insect Physiology and Ecology (ICIPE) group. This speculation was made because surveys from the previous years from Ethiopia did not report *C. flavipes*. Another reason for the speculation was that the highest rate of *C. favipes* parasitism was from eastern Ethiopia, which is in close proximity to the Somalia release site. This parasitoid has a very good potential in suppressing stem borers' population in Ethiopia, as the mean parasitism rate for 2005/06 was 58% (Emana *et al*., 2008). Melaku *et al*., (2006b) from their survey of 2003 and 2004 in the Amhara Region of northern Ethiopia reported that *C. flavipes* was the most abundant parasitoid species in the semi-arid eastern Amhara with an overall average of around 30% parasitism, although as high as 85% parasitism was recorded in many localities. Emana *et al*., (2003a) recorded as high as 100% parasitism in a few eastern Ethiopian localities. Emana (2007) studied different biological parameters such as life table, developmental time, fecundity and longevity of Asian populations of *C. flavipes* under different temperature and relative humidity conditions. The information obtained from these studies helped to demarcate the release sites of *C. flavipes* for the future successful biological control of *C. partellus.*

Host range study of stem borers

This study was conducted at Bako, Nazret and Arsi-Negele. The results obtained indicated that over 62 grass species were recorded as hosts for stem borers in Ethiopia near maize and sorghum crops. About 10 different species of arthropods were also found on both the crops and wild grasses. Some larval and pupal parasitoids were also reared from borers collected from cultivated and wild grasses (Emana, 2004). Elephant grass (*Pennisetum purpureum*) and wild sorghum (*Sorghum verticilliflorum*) were identified as potential hosts of stem borers for larval development and their survival.

Yield Loss Assessement Studies

Stem Borers

Yield losses reported due to stem borers varied greatly. Emana and Tsedeke (1999) reported yield losses ranging from 10 to 100% from Arsi-Negele. Emana (2002a) reported yield losses of 28% due to stem borers in Ethiopia. Tsedeke and Tesfahun (2003) reported a loss of 58% due to stem borers on late planted maize. Melaku *et al*. (2006a) reported 49% grain yield losses due to stem borers in northern Ethiopia. The average yield losses can be estimated between 20 and 50%.

Termites

Abraham (1988) reported 45, 50 and 18% yield losses due to termites at Bako, Didessa and Asossa, respectively. Offgaa (2004) studied the status of termites in western Ethiopian Manasibu district on different vegetation types such as crop lands, forest area, grazing land and homestead. He recorded up to 100% losses on maize. He indicated that ecological rehabilitation, restricting the herd size on grazing land, growing resistant indigenous plants in strips of rangeland and crop field significantly reduced losses due to termites and enabled the coexistence of termites with the vegetation without much loss.

Management Practices of Stem Borers and Termites

Stem borers

Cultural practices

Sowing date: In Ethiopia, a number of experiments on sowing date effects on stem borer damage were conducted. However, the results obtained were variable. Contrary to what was known in the past, early planting in Ethiopia averted stem borer damage. Melaku *et al*. (2006b) reported decreasing borer populations and damage with delays in planting in Addis Zemen areas of the Amhara region. This indicated that in northern Ethiopia where there was one effective rainy season and long dry season, the borer incidence behaved differently from regions receiving bimodal rainfall in the country such as Hawassa, Ziway, Adama, and Sirinka. Such a situation could also arise from the current climate change. Therefore, early or late planting can be recommended in different areas. Even the term early is relative as it is linked to the onset of rainfall. For example, early sowing for Hawassa and Arsi-Negele is in mid to the end of April, while early sowing for Ziway, Melkasa and Meiso is in mid to the end of June. In general, most experiments recommended early planting, while a few of them recommended late planting, which suggests the need for optimizing sowing dates based on location.

Intercropping: In Ethiopia, a considerable number of farmers practice intercropping maize with other crops (Emana, 2002a; Emana *et al*., 2003b). The major companion crops are legumes, cereals, pumpkin, groundnut, sesame, mustard, potato and sweet potato depending on the region. Intercropping has many advantages over mono-cropping including pest control. Much of the published research indicates that intercropping maize with legumes reduces the infestation of stem borers and increases abundance of their natural enemies which is explained by resource concentration and natural enemy hypotheses. Emana (2002a) reported lower stem borer density per plant in maize intercropping with haricot bean and cowpea than mono-cropping in his experiments conducted in Hawassa, Melkasa and Meiso. Furthermore, Girma (1996) reported that intercropping maize with beans also delayed the onset of stem borer infestation. On the other hand Getahun (2003) reported that the mean number of stem borers' larvae per maize stem was found significantly lower under chat (*Catha edulis*)–maize intercropping than maize mono-crops. In the laboratory observations, higher numbers of parasitoid cocoons were recorded on the intercropped plot than the mono-cropped plot (Getahun, 2003). Melaku *et al*. (2007) studied the effect of cropping systems (haricot bean, sesame and sweet potato in eastern Amhara and faba bean, mustard, cowpea, and potatoes in western Amhara) on the infestation of stem borers. He concluded that the cropping system had little effect on the infestation of maize by the stem borer, *C. partellus,* while the plots assigned to mustard significantly reduced borer density and damage caused by *B. fusca* especially at the vegetative stage.

***Effect of fertilizer on stem borer infestation*:** Emana (2002a) reported that stem borer infestation was high in the soil where total N was high. A field experiment was also conducted to study the effect of NPK fertilizers on the infestation of stem borers and the preliminary result indicated that high levels of N favored stem borer infestation. Melaku *et al*. (2006a) reported similar results from northern Ethiopia where they indicated that in the cool-wet western Amhara, increasing levels of N fertilizer also tended to increase pest density, plant growth, and damage variables. In semi-arid eastern Amhara, the effects of fertilizer on pest damage and yield were low because of the inherent high soil fertility status. The results indicate that the profitability of nitrogen fertilizer as an integrated pest management tactic in the control of cereal stem borers depended on the severity of borer damage and the soil fertility status prevailing in an area among others (Melaku *et al.,* 2006a). Generally, it was concluded that even though N fertilizer helped to minimize the impact of borers on grain yield, considering the importance of fertilizer for yield increment it is advisable to use other management options for the control of stem borers.

Habitat management: push-pull strategy

Delenasaw (2004) and Delenasaw *et al*. (2008) studied five wild hosts used as trap plants against *C. partellus* and found variability among the wild hosts. The wild hosts tested were *Pennisetum purpurum* (Scumach), *Sorghum vulgare* var. Sudanese (Pers.), *Panicum maximum* Jacq., *Sorghum arundinaceum* Stapf and *Hyperrhania rufa* (Nees). The results of the studies showed that maize plots surrounded by all tested wild hosts showed significantly (P<0.05) lower mean percent foliar infestation and stem borer density than maize mono-crop plots 15 m away from the treatment blocks. Percentage tunneled stalks was significantly (P<0.05) greater in maize mono-crop plots than maize plots surrounded by all tested wild host plant species. The highest mean percent parasitism (67%) of *C. partellus* (Swinhoe) by *C. flavipes* (Cameron) was recorded on maize plots surrounded by *P. purpurem* and intercropped with silver leaf dismodium (*Desmodium uncinatum)*. The findings showed that these wild hosts have considerable merit to be used as trap and repellent plants in the development of strategies for managing stem borers in maize crops.

Screening of Napier grass (*Pennistum purpurium*) accessions for the management of maize stalk borer was carried out in green house conditions at Hawassa Agricultural Research Center in 2001 and 2002. The same experiment was also conducted at Bako in 2001 and 2002 (BNMRP, 2003). Out of 61 accessions, five susceptible Napier grass accessions were selected and evaluated under field conditions at Hawassa and Areka Agricultural Research Centers in the southern and at Ehud-Gebeya in the western region during 2003 and 2004. The results obtained from Hawassa and Areka were not conclusive since there were no statistically significant differences among treatments (HNMRP, 2005). However, the result obtained from Ehud-Gebeya indicated that maize plots surrounded by Napier grass and intercropped with silver leaf desmodium significantly (P<0.05) lowered mean percent foliar damage and stem borer density compared with maize mono-crop plots 20 m away from the treatment blocks. Percentage tunneled stalks was significantly (P<0.05) greater in maize mono-crop plots than maize plots surrounded by napier grass and intercropped with silver leaf desmodium (Girma and Addis, unpublished data). The method of application of the strategy and mode of actions are shown in Fig. 1.

Use of botanicals

Chat (*Catha edulis*) leaf extracts inhibited the larval feeding activity and caused larval mortality in stem borers (Tekle, 2002). Oils extracted from *Azadarachta indica*, *Haggenia abbysinica* and *Mellitia furregemia* gave 100% mortality at 5% concentration (EARO, 2004).

Field evaluation of dust and spray application of botanicals against *B. fusca* was conducted at Hawassa during 2003 and 2004 cropping season. The botanicals evaluated were *Croton macrostachys* leaf, *Chenopodium ambrosoides* leaf, *Datura stramonium* leaf, *Vernonia amygdolina* leaf, *Nicotinia tobacum* leaf and stem, *Tagatuse minuta* leaf, *Solanium incunum* fruit, *Allium sativum* bulb, *Eucalyptus globules* leaf, neem seed, *Calusia abyssinica* leaf. The results showed that lower numbers of exit holes, larva, tunnel length (cm) and % of cobs damaged by *B. fusca* were obtained from dust application of *D. stromonium*, *N. tobacum* and *E. globules* leaf treated plots (HNMRP, 2005).

Use of resistant varieties

Plant resistance is the most important component of an integrated pest management system. The phenomenon of plant resistance to insects is a quality that enables a plant genotype to avoid, tolerate, or recover from the effects of oviposition or feeding that would cause greater damage to other genotypes of the same species under similar environmental conditions. Resistance is measurable, i.e., the mechanisms and magnitude of resistance can be qualitatively or quantitatively determined by analysis of insect behavioral and metabolic responses to the host, and by assessment of plant growth and development in response to insect feeding and oviposition. The resistance in plants affects oviposition, feeding, growth and development of the insect (Habib, 2005). Maize varieties differ greatly in their intrinsic susceptibility to stem borers. Some fruitful research has been done to develop stem borer resistant maize varieties. In Kenya ten stem borer resistant hybrids and open-pollinated varieties (OPVs) were released by The Insect Resistant Maize for Africa (IRMA) project (Mugo *et al*., 2008).

However, in Ethiopia very little research on genotypic resistance has been done so far. Seven released maize genotypes (Guto, BH140, BH660, BH540, ACV3, ACV6, Kuleni) were evaluated for their resistance to maize stem borer, *B. fusca*, at Hawassa. None of the varieties showed resistance to the pest. Eight maize varieties from CIMMYT and Bako were also tested against *B. fusca* in the laboratory and field at Ambo. The results indicated that were some differences in resistance. Of those varieties evaluated, PR85A-2B, PR85A-251, TL82A-1071, UCA and KCB were found to be more tolerant to the pest. Large numbers of maize genotypes were screened against

(b)

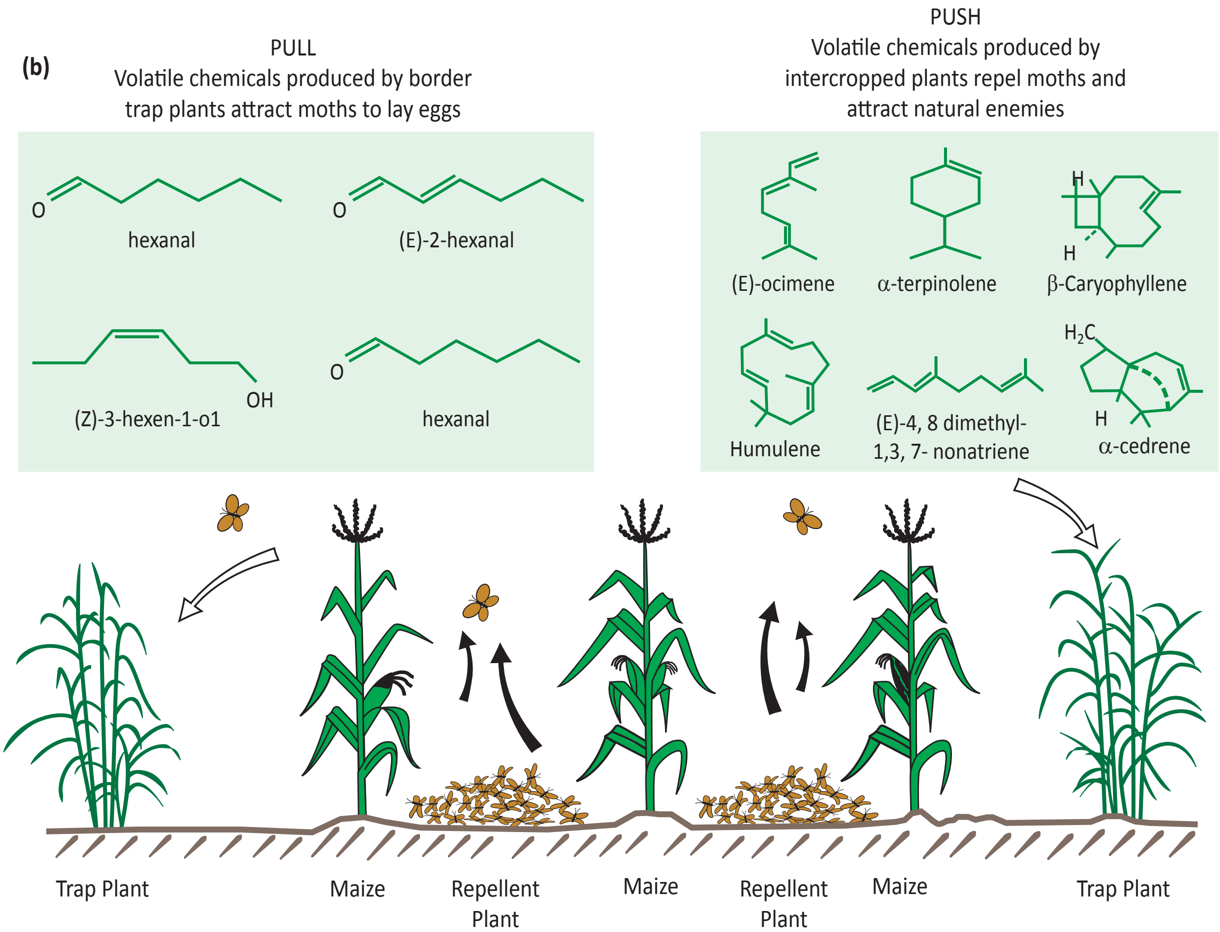

Figure.1 (a) Application method of push-pull strategy and (b) mode of action for push-pull strategy .

C. partellus at Melkasa (Sefedin, 2006). The results showed variations in infestation among the genotypes. In 2009, 28 stem borer resistant maize varieties were introduced from IRMA II project (Kenya) to test their local adaptability and resistance to the pests. From those introduced materials 10 best performing and resistant varieties were identified for further multi-location testing (BNMRP, 2010). Parental lines for both selected varieties were also introduced to test their adaptability and resistance as well as increase their seed locally.

Biological control of stem borers

Among parasitoids, *C. flavipes* was mass reared in the laboratory and released at Wolenchti, Meiso and Melkasa in 2004. A recovery/establishment survey was conducted in 2005 and parasitism in all the three areas ranged between 75 and 87% which was over 50% increment when compared to the 2003 parasitism (Emana, 2005). In Ethiopia, *C. flavipes* created a new association with certain populations of *B. fusca* under field conditions. Parasitism under field conditions could be due to multiple parasitisms as *C. sesamiae* and *C. flavipes* can occur together in the field. Hence, a suitability study under laboratory conditions was conducted to confirm the suitability. The results obtained indicated that only two populations of *B. fusca* were found to be suitable hosts to all populations of *C. flavipes*. After the data were corrected for natural mortality, no significant differences were observed between *C. partellus* and *Sesamia calamistis*, but both populations of *B. fusca* were inferior to them in terms of suitability (Emana, 2002b). Other studies were conducted on pathogens with isolates of entomopathogenic fungi *Beauveria bassiana* and *Metarrhizium anisopliae* from Ethiopia against spotted stem borer, *C. partellus* (Tadele, 2004a, b, 2005). Four isolates of *B. bassiana* and six isolates of *M. aniopliae* were tested against second instar larvae. Of these isolates, *B. bassiana* (BB-01) and *M. anisopliae* (PPRC-4, PPRC-19, PPRC-61 and EE-01) were found to be highly pathogenic inducing 90–100% mortality seven days after treatment.

Chemical control of stem borers

Recommendation of some chemicals for the control of stem borers has been done since 2001. Verification of Ethiodemethrin 2.5% WDP insecticide against maize stem borer was conducted at Bako, Sire and Ehud-Gebeya in 2008. The results showed that there were significant differences in damage variables and grain yield between treated and untreated plots. All damage variables were significantly ($P<0.05$) lower in Ethiodemethrin treated plots than in the unprotected plots, whereas, the grain yield was significantly ($P<0.05$) higher in protected than in the unprotected plot (Girma, 2008). Similarly, verification of Decitab was carried out on farmers' fields at Hawassa, Arsi Negelle and Areka to verify the efficacy of Decitab against the maize stalk borer (*B. fuscsa*). Significantly lower percent of infested plants/plot, number of exit holes and tunnel length/plant were recorded from Decitab treated plots. Generally, application of Decitab at 4 and 6 weeks after emergence of maize plants at the rate of 10 g of a.i. per hectare can control maize stalk borer (*B. fusca*) (HNMRP, 2004).

Termites

Cultural practices

***Intercropping and mulching*:** Girma *et al.* (2009) studied the effect of mulching and intercropping on termite damage at Bako during 2005 and 2006. A total of four treatments, *viz*. maize intercropped with soybean, maize stover as mulch, neem seed powder as mulch and simultaneous use of mulching and intercropping were tested with sole maize as a control and Diazinon 60% EC at 2 l ha^{-1} as a treated check. Analysis of variance for seasonal means of percentages of root damage, stem damage and cob damage by termites during the two cropping seasons showed significant differences between the treated and untreated plots (Table 1). Damage was significantly ($P<0.05$) lower in treated plots than in the untreated plots in both seasons.

Grain yield, field weight and number of plants at harvest were significantly greater ($P<0.05$) in plots treated with both intercropping and mulching than the other treatments in both cropping seasons (Table 2). On the other hand, yield per plot (40.7 kg, 23.6 kg) and number of plants at harvest (281, 336) were significantly lower in the untreated plot in both 2005 and 2006 cropping seasons, respectively. There was a yield gain over the untreated maize of 12% in the simultaneous use of mulch and intercropping (Girma *et al*., 2009).

Botanical control

Getahun (2003), and Getahun and Bekele (2006) reported that extracts of seed powder of *M. ferruginea* and *A. indica*, fresh stem bark of *C. macrostachyus* showed higher toxic effects on different termite casts.

Biological control

Metahrizium anisopliae and Enthomopathogenic Nematode (EPN) were reported to be effective against termites (APPRC, 2010; Girma, 2011).

Chemical control

The effectiveness of fipronil (Regent 500 FS) as seed treatment for the control of termites on maize was evaluated at Bako from 2001 to 2003. Five rates of fipronil (6.7, 8.3, 10.0, 11.7 and 13.3 ml kg^{-1} of maize) and untreated control were evaluated. Results showed that the optimum rates of fipronil for the control of termites were 8.3, 10, 11.7 and 13.3 ml kg^{-1}, which resulted in low percent root, stem and cob damage and on the contrary resulted in high yield (Girma and Demissew, unpublished data). Verification of GUFOS (Chlorpyrifos 48% EC) against termites attacking maize at Bako was carried out in 2007. The result showed that GUFOS was as effective as the standard insecticide diazinon 60% EC (Girma, 2008). It can be recommended for use as an alternative in the management of termite in maize. Verifications of different insecticides were conducted by the Maize Protection Research Team of Bako National Maize Research project in 2009 and 2010. The results showed that dressing maize seeds with SeedPlus 30WS at the rate of 10 g/2 kg of seeds, and spraying of Ethiopyrifos 48% EC from China at the rate of 200 ml ha^{-1} did protect maize from the attack of termites as compared to untreated check (Girma, 2011).

Table 1. Percentages of maize plants with root, stem and cob damage caused by termites in different treatments.

Treatments	Damaged maize (%)		
	Root	Stem	Cob
	First cropping season (2005)		
Untreated control	17.9 ± 3.1a	7.1 ± 0.3a	4.3 ± 2.1a
Diazinone 60% EC	7.3 ± 3.7b	1.3 ± 0.5c	0.4 ± 0.4b
Neem seed powder	8.8 ± 0.8b	3.2 ± 0.9bc	1.1 ± 0.5b
Intercrop with soybean	9.0 ± 4.5 b	3.7 ± 0.4b	0.7 ± 0.2b
Intercrop + mulch	9.6 ± 4.8b	4.1 ± 0.3ab	0.7 ± 0.5b
Maize Stover as mulch	9.6 ± 1.6b	5.6 ± 2.0ab	2.4 ± 0.6ab
CV (%)	20.8	12.6	23.62
	Second cropping season (2006)		
Untreated control	12.15 ± 8.45a	3.90 ± 1.70a	6.1 ± 1.3a
Diazinone 60% EC	3.50 ± 3.50b	1.10 ± 0.30ab	2.4 ± 1.9ab
Neem seed powder	3.75 ± 3.75b	0.70 ± 0.40b	3.7 ± 0.1ab
Intercrop with soybean	2.95 ± 2.95b	0.95 ± 0.25b	1.7 ± 0.3b
Intercrop + mulch	4.35 ± 1.35b	1.00 ± 0.03b	2.5 ± 1.2ab
Maize stover as mulch	3.35 ± 1.55b	0.85 ± 0.15b	1.7 ± 0.2b
CV (%)	39.54	23.49	24.53

Source: Girma *et al*. (2009). For each cropping season means within a column followed by the same letter(s) are not significantly different at P ≤ 0.05. CV = coefficient of variance.

Table 2. Number of plants at harvest (NAH) and average grain yield of maize from plots with different treatments in two growing seasons.

Season	Treatments	NAH	Yield (kg $plot^{-1}$)
2005	Untreated control	281 ± 3.0b	40.75 ± 0.44c
	Diazinone 60% EC	371.5 ± 13.5a	49.56 ± 0.98b
	Neem seed powder	345.5 ± 3.5a	52.98 ± 0.39ab
	Intercrop with soya bean	356.5 ± 22.5a	53.93 ± 2.28ab
	Intercrop + mulch	381.5 ± 38.5a	58.50 ± 4.23a
	Maize Stover as mulch	347 ± 3.5a	48.07 ± 1.59bc
	CV (%)	3.69	6.29
2006	Untreated control	336.5 ± 50.5b	23.60 ± 6.28d
	Diazinone 60% EC	393 ± 15.0a	30.08 ± 1.37bcd
	Neem seed powder	342.5 ± 37.5b	31.51 ± 2.98bc
	Intercrop with soya bean	406 ± 9.0a	36.86 ± 6.98ab
	Intercrop + mulch	414 ± 5.0a	39.61 ± 4.92a
	Maize Stover as mulch	413.5 ± 2.5a	26.25 ± 3.62cd
	CV (%)	4.76	9.54

Source: Girma *et al*. (2009). Means followed by the same letter in a column within growing seasons do not differ significantly at P ≤ 0.05. CV = coefficient of variance.

Conclusions and Future Research Directions

In general, various attempts have been made for the past decade to generate stem borer and termite control methods in maize. Considerable information which substantially contributes to the country's food self-sufficiency program has been generated by different research institutions. Losses caused by termites and stem borers have been determined. Relatively extensive information has been accumulated from studies of stem borers. However, very little research has been done on termites despite the magnitude of the problem. Studies were conducted in the area of insecticide screening, cultural control, botanical control, biological control and varietal resistance. Some of these studies generated base-line information rather than technologies for immediate use. No resistant varieties have been developed so far. Varietal screening requires mass rearing of large numbers of insects for artificial infestation. An entomologist without a well-equipped laboratory and green house facilities cannot accomplish his duty to these expectations.

In spite of the various accomplishments achieved so far, there are a number of challenges to be addressed in the future to accommodate the gaps. The following are suggested for future research directions:

- Development of sound integrated pest management options from the existing control options.
- Dissemination of stem borer and termite management technologies by;
  - ♦ Organizing field days, exhibitions, field demonstration trials, etc
  - ♦ Production of booklets, posters, brochures etc. to be used as manuals by development agents and farmers
- Development of resistant varieties against stem borers.
- Commercialization and utilization of Entomopathogenic fungus and natural enemies associated with termites and stem borers such as *B. bassiana*, *M. anisopliae* and *C. flavipes* for the biological control of termites and stem borers.
- Importation of new emerging stalk borer and termite management technologies from abroad.
- Periodical updating of information on the status of stem borers, their natural enemies, environmental factors etc in order to tackle newly emerging problems.
- Research on the biology, ecology and management of termites should be continued.
- Establishment of well-equipped insectaries.

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Maize Stalk Borers of Ethiopia: Quantitative Data on Ecology and Management

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Introduction

Maize is the most important food security crop for Ethiopia, as it is for many other countries in sub-Saharan Africa. The average annual rate of growth in area and yield has been increasing over the last four decades (FAOSTAT, 2008). Growth in productivity has been more pronounced since the early 1990s, indicating possible impacts of maize research and development efforts. This is an encouraging growth rate, but still falls short of a three- to four-fold increase potential that could be achieved using even currently existing technologies.

Pest problems, coupled with recurrent drought and decline in soil fertility are some of the major constraints to increase maize productivity and production in Ethiopia. Stalk borers rank the highest amongst the pests that damage this crop. Quantitative data on the economic importance of this particular pest are of particular significance in setting priorities for management interventions. I am aware that much work has been done on maize entomology in Ethiopia and papers would be presented on this subject at this workshop. My intention is not to repeat those but to give my personal experience based on the work my colleagues and I carried out from Melkasa Research Centre of the Ethiopian Institute of Agricultural Research (EIAR) during the period 1996–1998. My presentation focuses on quantitative data dealing with the insect distribution and significance, natural enemy composition and their population dynamics, and control measures. My original work compared the importance of stalk borers on maize and sorghum but I will concentrate here on maize.

Methodology

Distribution and significance

Intensive surveys were conducted across major sorghum and maize growing areas of Ethiopia during the 1996 and 1997 main cropping seasons (Fig. 1).

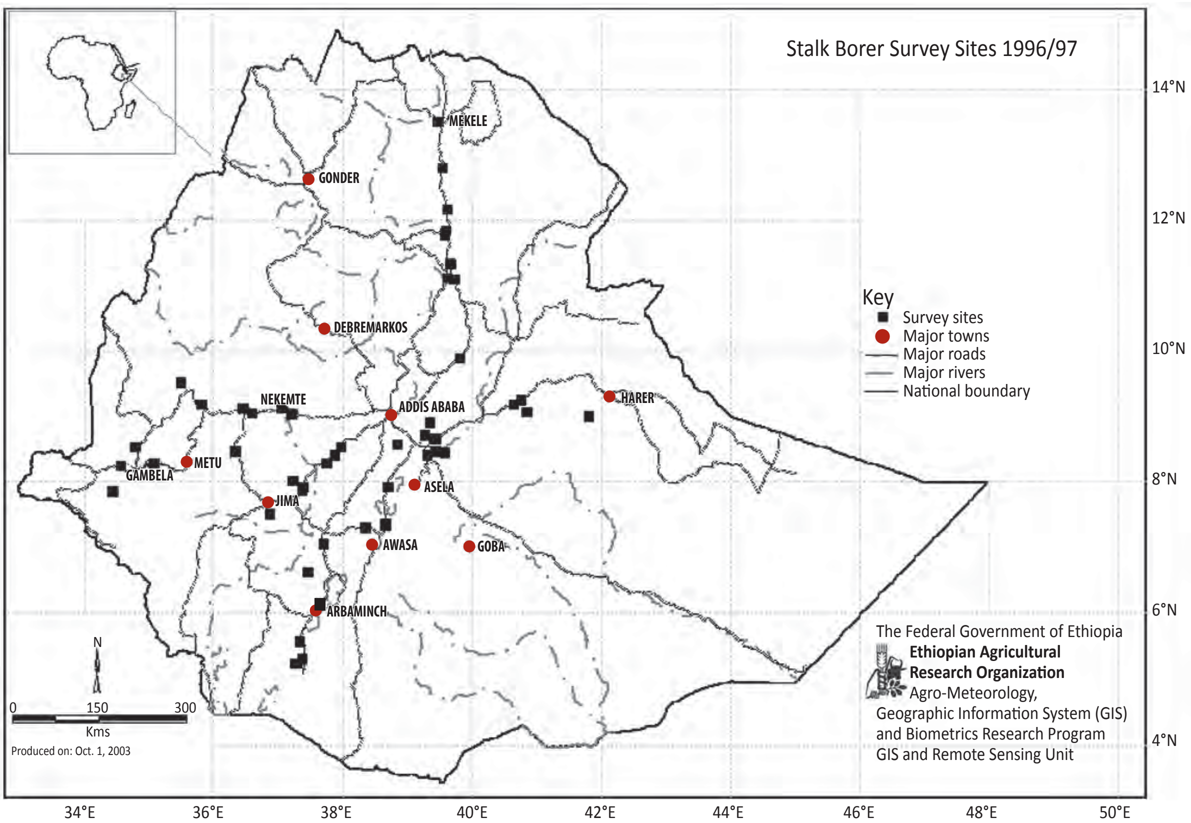

Figure 1. Survey sites.

Samples of whole matured plants were collected from as many areas as possible and taken to the laboratory where they were dissected and numbers of exit holes and stalk borers (consisting of larvae of various instars, pupae, and pupal cases) were recorded for each plant sample. Stalk borer species and their composition were determined for each sample site. Records of larvae and pupae (including pupal cases) were made for each of the stalk borer species. Percentages of infested plants were determined on the basis of presence or absence of stalk borers, or their damage symptoms – i.e., exit holes. Altitude (meters above sea level; masl) was recorded for each sample site using an altimeter.

Normally, sample size ranged between 20 and 50 per site. Larger numbers of plants were collected from research stations, substations or testing sites than from farmers' fields. Samples for research center, substation and testing site were taken from production or seed multiplication fields and various agronomic or breeding trials. A total of 1,042 maize plants were sampled from 25 major maize growing sites across the country.

Natural enemies

The plant samples mentioned above were taken to the laboratory where they were dissected, and numbers of stalk borers and natural enemies were recorded for each plant. Some of the plants containing the stalk borers (larvae and pupae) were kept in Plexi-glass cages in the laboratory until adult moths or parasitoid wasps emerged. Predators were counted at the time of dissection of stalks. Natural enemies were identified by comparing the specimens with locally available collections and using the literature; those that could not be identified locally were sent to the CABI International Institute of Entomology for identification or confirmation.

Studies on field biology

This experiment was superimposed on another experiment that investigated the effects of sowing date, crops and neem seed powder treatment on the field biology of *Chilo partellus* and its natural enemies at the Melkasa Research Centre of EIAR (also see below).

The experiment was conducted in a split-split plot (all data presented here are only from untreated maize plots; thus sub-sub plot details are not shown), laid out in a randomized complete block design replicated twice. Main plot treatments included sowing date and subplot treatments were crops (sorghum, cv. '76T_1#23' and maize cv. 'ACV3'). A recommended standard spacing of 75 cm between rows and 10 cm between plants was used for growing sorghum whereas maize was grown at 75 cm between rows and 30 cm between plants. Plots for both crops were 4.5 m long and 3.75 m wide; thus there were a total of five rows per plot. Therefore, theoretically, each plot consisted of 75 maize plants.

Planting was carried out monthly, for 24 months, from January 1997 to December 1998. A recommended fertilizer, DAP, was applied at the rate of 100 kg ha^{-1}, and supplementary irrigation was provided as needed. Stand counts were recorded within 2 weeks of seedling emergence. Data on egg counts, leaf damage, borer density and pupation were recorded at various stages of the plant growth.

Eggs were counted by walking diagonally along each plot; leaves of plants within a 1m row were thoroughly examined and the number of egg batches observed was recorded. Counts were taken for 6 weeks starting from 3 weeks after seedling emergence (wae). Number of seedlings showing general leaf damage (such as window holes) was also recorded for each plot, starting at 3 wae. Borer density (i.e., number of borers per given number of plants) was recorded at 8 and 10 wae and at harvest.

Borer density at 8 and 10 wae was determined by using "destructive sampling". A total of 10 plants were uprooted from each plot by walking along each diagonal and were taken to the laboratory, where the number of borers for each plant were recorded separately; counts of larvae and pupae were recorded accordingly. Counts were taken on 20 randomly selected plants per plot at harvest. Percentages of pupating borers were computed at 8 wae, 10 wae and at harvest.

Determining the effects of neem seed powder on stalk borers

The same experiment was also used to determine the effects of neem seed powder on stalk borers. Fresh samples of mature seed of neem (*Azadirachta indica*) were supplied, as needed, by the Dire Dawa Regional Agricultural Bureau; these were dried under subdued light (not directly exposed to sun heat) in the laboratory at the Melkasa Agricultural Research Centre of EIAR. The dried seed was ground to a fine powder and mixed with pure sand in a ratio of 1:1 by volume. A pinch of the neem-sand mixture was applied in the whorls. Application rate was about 5 kg ha^{-1} of neem seed powder.

Effects of sowing date and insecticide treatments

Field experiments were carried out during two main crop seasons (1997 and 1998) at Melkasa and during one season (1997) at Hawassa and Arsi-Negele research centers of EIAR. The experiment was laid out in a randomized complete block design with split plots, in two replications, at all locations. Main plot treatments included four sowing dates whereas subplots were three levels of insecticide application. Replications, main plots, and subplots were separated by 2.5 m, 2 m, and 1.5 m, respectively, so that the gross area of the experiment was 1,176 m^2. Each subplot was 6 m x 6 m; row spacing was 75 cm and plants were spaced 30 cm apart.

Results and Discussion

Stalk borer infestation ranged from nil at Didessa to 100% at Nejo (Table 1). The overall average infestation was about 60%. Similarly, average number of borer exit holes per plant ranged from 0 at Didessa to 23.8 at Nejo (overall mean 3.4). With the exception of samples collected from sowing date trials at Ziway, stalk borers per maize plant were generally low. It was only at Nejo that more than 1 stalk borer per plant was recorded.

Highly significant correlations were observed between percent infested plants and exit holes (r = 0.648, P = 0.001), percent infested plants and stalk borers per plant (r = 0.776, P = 0.000), and exit holes and stalk borers per plant (r = 0.795, P = 0.000). One or more species of stalk borer were recorded in maize, except in four locations – namely, Korga (some 50 km south of Wolaita Sodo, on the road to Arba-Minch), Didessa, Bako, and Odaharo (near Bako-Tibe). *Busseola fusca* was recorded at altitudes ranging from 530 to 1,950 masl; whereas *C. partellus* was found up to 1,850 masl. *Sesamia calamistis* was recorded only at two locations – Omolante and Elbacho in southern Ethiopia. In general, *B. fusca* was more widely distributed and relatively more important than *C. partellus* in maize and accounted for nearly 90% of the total number of borers (902) recorded at all locations. *C. partellus* and *S. calamistis* constituted about 8% and 1% of the total population, respectively. The remaining 1% was accounted for by *C. sesamiae* parasitization. *S. calamistis* was recorded at 3 of the 25 sampling sites; at Omolante it was the only species observed whereas at Elbacho and Adulala it accounted for approximately 25% and 4.8%, respectively (Table 1).

Pupation occurred in both *B. fusca* and *C. partellus* at several locations. Pupae and pupal cases of *B. fusca* were observed at Gimbi, Nejo, Sirinka, and Ziway. Pupation in *C. partellus* was high especially at Gambella and Sirinka, with lesser percentages at Welenchiti, Melkasa, and Bofa (Fig. 2).Past efforts on stalk borer research in Ethiopia concentrated on *B. fusca*, mainly in

Table 1. Percent infestation and damage by major stalk borers, their relative abundance and composition in maize at different locations in Ethiopia – 1996 and 1997 main crop seasons.

Location	Alt. (masl)	Sampling date	Infestation (%)	Holes/ plant	Borers/ plant	Percent composition *Busseola*	*Chilo*	*Sesamia*
Gambella	530	08.01.98	33.3	2.6	0.3 ± 0.1	12.5	62.5	0.0
Bofa	1,200	03.12.96	48.3	1.6	0.2 ± 0.1	7.1	92.9	0.0
Korga	1,200	26.12.96	70.0	1.6	0.0 ± 0.0	0.0	0.0	0.0
Omolante	1,230	31.12.96	80.0	1.9	0.3 ± 0.2	0.0	0.0	100.0
Elbacho	1,250	31.12.96	65.0	4.5	0.6 ± 0.2	16.7	5.0	25.0
Didessa	1,350	26.12.97	0.0	0.0	0.0 ± 0.0	0.0	0.0	0.0
Welenchiti	1,400	29.11.96	78.0	4.9	0.7 ± 0.2	17.6	76.5	0.0
Melkasa	1,550	06.12.96	20.0	0.3	0.1 ± 0.0	50.0	50.0	0.0
Adulala	1,580	04.12.96	40.0	0.9	0.2 ± 0.1	81.0	4.8	4.8
Bako	1,650	06.01.98	18.0	0.4	0.0 ± 0.0	0.0	0.0	0.0
Odaharo	1,650	09.01.98	8.0	0.4	0.0 ± 0.0	0.0	0.0	0.0
Ziway1†	1,700	30.09.97	95.0	– ††	13.2 ± 3.3	99.2	0.8	0.0
Ziway2	1,700	30.09.97	95.0	–	11.9 ± 2.0	100.0	0.0	0.0
Ziway3	1,700	30.09.97	85.0	–	3.6 ± 0.8	98.6	1.4	0.0
Ziway4	1,700	30.09.97	95.0	–	3.5 ± 0.5	94.3	5.7	0.0
Ziway †††	1,700	25.12.96	63.6	2.5	0.9 ± 0.3	100.0	0.0	0.0
Lencha-Tika	1,800	25.12.96	95.0	9.4	0.9 ± 0.2	94.1	0.0	0.0
Arsi-Negele	1,800	19.12.96	78.0	2.8	0.5 ± 0.1	96.0	0.0	0.0
Sekoru	1,810	08.01.98	32.0	1.8	0.3 ± 0.2	80.0	0.0	0.0
Sirinka	1,810	06.01.97	50.0	1.6	0.3 ± 0.1	50.0	50.0	0.0
Dembi-Dolo	1,850	07.01.98	36.0	1.9	0.2 ± 0.1	75.0	25.0	0.0
Nejo	1,860	06.01.98	100.0	23.8	1.3 ± 0.2	97.0	0.0	0.0
Gimbi	1,900	06.01.98	36.0	3.5	0.1 ± 0.1	100.0	0.0	0.0
Bedele	1,935	08.01.98	40.0	4.1	0.1 ± 0.1	100.0	0.0	0.0
Keta	1,950	31.12.96	36.0	0.8	0.1 ± 0.1	100.0	0.0	0.0

†SD1, SD2, SD3 and SD4 refer to sowing dates of 27 June, 4 July, 11 July, and 18 July 1997 at Ethiopian Institute of Agricultural Research station, ††Not recorded, †††Samples from a farmer's field.

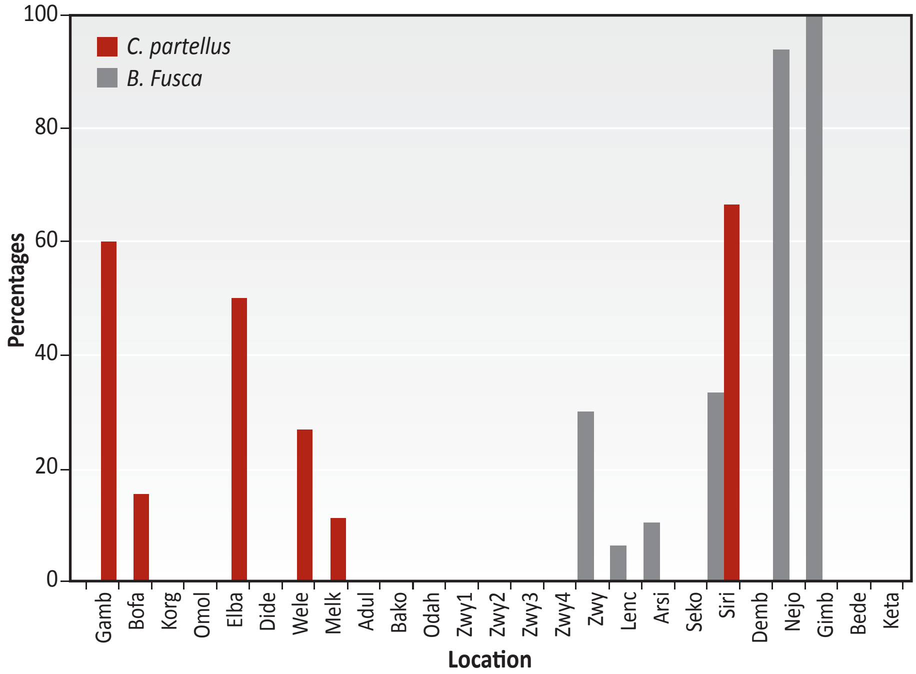

Figure 2. Percent pupation of *Busseola fusca* and *Chilo partellus* in maize at different locations in Ethiopia (see Table 1 for full names of locations).

maize, and there has been a notion that this species is more important than *C. partellus*. However, our results indicated that the latter is more important in sorghum. Our results also suggested that *S. calamistis* is economically the least important of the three stalk borers in Ethiopia, at least in the areas covered in this survey.

B. fusca is known to go into diapause during the extreme weather conditions in Ethiopia and many other parts of Africa (Gebre-Amlak *et al.,* 1989; Yitaferu *et al.,* 1994; Kfir 1998); there were no indications that *C. partellus* goes into diapause in Ethiopia. However, it is known to undergo diapause in northern India during the winter season. It is interesting to note here that significant numbers of *B. fusca* collected during the current survey pupated, even though the sampling was made very well into the dry season in most of the areas covered. This suggested the possibility that overlapping generations of *B. fusca* could occur and therefore continually infest the crop, given the right environmental conditions.

The strong correlations between percent plants infested, exit holes per plant, and stalk borers per plant suggested that any one of these parameters could be used to measure the damage by lepidopterous stalk borers. However, stalk borer counts should be given preference over exit holes because they are the surest way of determining stalk borer damage. Percent infestation is not a reliable measure of stalk borer damage, as it might not be necessarily correlated with yield loss.

Natural enemies

Table 2 shows the list of natural enemy complex of stalk borers in survey sites in Ethiopia. Brief accounts of these are presented below.

Larval parasitoids

***Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae)**
This gregarious larval parasitoid is widely distributed in maize and sorghum producing areas of Ethiopia (Table 2). It is perhaps the most important larval parasitoid of *B. fusca* and *C. partellus* in this country. In maize, this parasitoid was recorded from 8 of the 25 sites sampled, ranging in altitude from 530 masl (Gambella) to 1,860 masl (Nejo). Maximum parasitization (about 25%) was recorded in the Gambella area; the next highest parasitization was recorded at Sekoru (20%). Kfir (1998) reported *C. sesamiae* to be the most important larval parasitoid of *B. fusca* and *C. partellus* in South Africa. *C. sesamiae* is known to be a polyphagous parasitoid of lepidopteran stalk borers in the families Crambidae, Noctuidae, and Pyralidae of Afro-tropical distribution (van Achterberg and Walker, 1998). Samples of *C. sesamiae* and *Cotesia flavipes* collected on 19 November 1996 emerged on 10 July 1997 in the laboratory at Melkasa.

Table 2. List of parasitoids and predators associated with major sorghum and maize stalk borers in Ethiopia – 1996 and 1997 crop seasons.

Taxon	Order: Family	Category
Cotesia sesamiae (Cameron)	Hymenoptera: Braconidae	Larval parasitoid
Cotesia flavipes (Cameron)	Hymenoptera: Braconidae	Larval parasitoid
Norbanus sp.	Hymenoptera: Pteromalidae	Larval parasitoid
Unidentified (seven species)	Diptera: Tachinidae	Larval parasitoids
Unidentified	Diptera: Phoridae	Larval parasitoid
Pediobius furvus (Gahan)	Hymenoptera: Eulophidae	Pupal parasitoid
Stenobracon rufus (Széplgeti)	Hymenoptera: Braconidae	Pupal parasitoid
Dentichasmias busseolae (Heinrich)	Hymenoptera: Ichneumonidae	Pupal parasitoid
Aphanogmus sp.	Hymenoptera: Ceraphronidae	Hyperparasitoid
Aphanogmus ?*fijiensis* (Ferriére)	Hymenoptera: Ceraphronidae	Hyperparasitoid
Eurytoma sp.	Hymenoptera: Eurytomidae	Hyperparasitoid
Eurytoma braconidis (Ferriére)	Hymenoptera: Eurytomidae	Hyperparasitoid
Exoristobia dipterae (Risbec)	Hymenoptera: Encyrtidae	Hyperparasitoid
Unidentified	Hymenoptera: Evaniidae	Hyperparasitoid
?*Pheidole* sp.	Hymenoptera: Formicidae	Predator
Unidentified	Hymenoptera: Formicidae	Predator
Diaperasticus erythrocephala (Olivier)	Dermaptera: Forficulidae	Predator
Unidentified species	Dermaptera: Forficulidae	Predator
Unidentified species	Dermaptera: Labiduridae	Predator
Anisochrysa boninensis (Okamoto)	Neuroptera: Chrysopidae	Predator
Adonia variegata (Goeze)	Coleoptera: Coccinellidae	Predator
Cheilomenes lunata (Fabricius)	Coleoptera: Coccinellidae	Predator
Cheilomenes propinqua (Mulsant)	Coleoptera: Coccinellidae	Predator
Cheilomenes vicinus (Mulsant)	Coleoptera: Coccinellidae	Predator
Platynaspis sp.	Coleoptera: Coccinellidae	Predator
Paederus sabaeus (Erichson)	Coleoptera: Staphylinidae	Predator
Philantus bisignathus (Boheman)	Coleoptera: Staphylinidae	Predator
Unidentified	Coleoptera: Carabidae	Predator
Unidentified	Hemiptera: Reduviidae	Predator
?*Chiracanthium* sp.	Araneida: Clubionidae	Predator
Unidentified	Araneida: Gnophosidae	Predator
Unidentified	Araneida: Thomisidae	Predator

Cotesia flavipes Cameron (Hymenoptera: Braconidae)
C. flavipes was particularly common on *B. fusca* in maize in the Ziway area. This parasitoid was introduced into Africa from the Indian sub-continent for biological control of stalk borers. It is known to have established in Kenya, Madagascar, and Mauritius (van Achterberg and Walker 1998). Its widespread distribution in Ethiopia is suspected to be the result of the introduction and release of stalk borer parasitoids for biological control of *Sesamia cretica* Lederer (Lepidoptera: Noctuidae) in the Asebot and the Mieso areas during the Italian occupation of Ethiopia in the early 1930s.

Norbanus sp. (Hymenoptera: Pteromalidae)

This external larval parasitoid was reared from *C. partellus* in sorghum samples collected in the Asebot area. It is known to be a gregarious ectoparasitoid of *S. cretica* in Sudan (Polaszek, 1998a).

Unidentified species (Diptera: Tachinidae and Diptera: Phoridae)
At least seven species of unidentified dipterous parasitoids (Tachinidae) and one species of Phoridae were reared from *C. partellus* attacking sorghum in the Melkasa area. These were reared only once from samples collected on 14 March 1997.

Pupal parasitoids

Pediobius furvus Gahan (Hymenoptera: Eulophidae)
This is the most important pupal parasitoid of *B. fusca* and *C. partellus* in maize and sorghum in Ethiopia. It is a gregarious primary parasitoid widely distributed in this country (Gebre-Amlak, 1985). Unlike *C. sesamiae*, it did not appear to undergo diapause as adult emergence was observed on the same day they were collected, and lasted for about one week (14–22 November 1996) in the

laboratory. Parasitization occurs almost throughout the year. For instance, the average pupal parasitization of *C. partellus* by *P. furvus* in sorghum and maize planted at monthly intervals for 2 years (between January 1997 and December 1998) ranged from 1.6% in October to 47.5% in July.

Stenobracon (=Euvipio) rufus **(Széplgeti) (Hymenoptera: Braconidae)**
This is a solitary pupal parasitoid of stalk borers attacking maize and sorghum in Ethiopia. Monthly average parasitization ranged from nil to more than 14%, with the highest average recorded in September. Relatively greater parasitization occurred from September to March. Elsewhere in Africa, *S. rufus* is known to attack pupae of *B. fusca*, *S. calamistis*, *Sesamia* sp., *C. partellus*, and *Eldana saccharina* (Walker) (van Achterberg and Walker, 1998).

Dentichasmias busseolae **Heinrich (Hymenoptera: Ichneumonidae)**
Parasitization by *D. busseolae* is generally lower than that by the preceding two species. However, it can reach up to 17% in some months. It is relatively more abundant during the wet seasons (in crops planted from May to July) in Melkasa. It was recorded on *C. partellus* pupae in maize and sorghum in the Melkasa area. Even though its main host is *C. partellus*, it has also been recorded from borers such as *S. calamistis* in Africa; *B. fusca* is not known to be its normal host (van Achterberg and Walker, 1998).

Hyper parasitoids

At least four species of hymenopterous hyperparasitoids were recorded in this study. Brief descriptions of each of these are presented below.

Aphanogmus **sp. and** ***A. fijiensis*** **(Ferrière) (Hymenoptera: Ceraphronidae)**
Both species attack cocoons of *C. sesamiae* and *C. flavipes*. These were recorded from *B. fusca* in maize in the Ziway area. *A. fijiensis* is known to attack hymenopterous parasitoids in the genera *Apanteles, Cotesia, Dolichogenidea*, and *Stenobracon*. It is widely distributed in Africa and elsewhere in the tropics (Polaszek, 1998b).

Eurytoma braconidis **Ferrière,** ***E. braconidis*** **Ferrière and** ***Eurytoma*** **sp. (Hymenoptera: Eurytomidae)**
The first two species were reared from *C. flavipes* attacking *B. fusca* in maize in the Ziway area; the last was reared from *C. sesamiae* in *C. partellus* in sorghum at Melkasa. From the literature, hosts of *E. braconidis* include the genera *Bracon* and *Stenobracon (=Euvipio)* attacking *C. partellus*, *Coniesta ignefusalis* (Hampson), *B. fusca, S. cretica* and *Sesamia* sp. (Polaszek *et al.,* 1998).

Exoristobia dipterae **(Risbec) (Hymenoptera: Encyrtidae)**
Reared from the same specimen that yielded *Norbanus* sp. attacking *C. partellus* in sorghum in the Asebot area. It is reported to usually attack Diptera (Polaszek *et al.,* 1998).

Unidentified species (Hymenoptera: Evaniidae)
Reared from an unidentified braconid wasp species attacking *B. fusca* in maize in the Arsi-Negele area. No other records.

Predators

Ladybird beetles (Coleoptera: Coccinellidae)
Several species of ladybird beetles were found in maize and sorghum fields. The most important species included *Cheilomenes lunata* (Fabricius), *C. propinqua* Mulsant*, C. vicinus* (Mulsant), *Adonia variegata* Goeze, and *Platynaspis* sp.; and two unidentified species. They are widely distributed in Ethiopia. Ladybird beetles are probably more important on aphids than on stalk borers. Their numbers usually declined from about 6 weeks (in maize) to 8 weeks (sorghum) after seedling emergence.

Paederus sabaeus **Erichson and** ***Philantus bisignathus*** **Boheman (Coleoptera: Staphylinidae)**
Both species were collected from maize fields in the Welenchiti area. They were more common in intercropped and weedy plots than in the maize monocrop. Both species had been recorded previously in bean fields at Hawassa (Abate, 1991). *Paederus* is known to be more abundant than *Philanthus*. Bonhof (1998) recorded a *Paederus* sp. attacking *C. partellus* eggs in Kenya. Van den Berg and Cock (2000) reported this species on various crops.

Anisochrysa boninensis **(Okamoto) (Neuroptera: Chrysopidae)**
This green lacewing was quite abundant in maize fields in the Welenchiti area; more common in intercropped and weedy plots than in maize monoculture. Widely distributed in mid- and lower-altitudes (below 1,700 masl) in Ethiopia, such as the Middle and Upper Awash valley where vegetables and cotton are cultivated extensively. A related species*, Chrysoperla* sp., is an important predator of African bollworm in Kenya (van den Berg and Cock, 2000).

Unidentified species (Hemiptera: Reduviidae)
This assassin bug was observed on *B. fusca* attacking maize in the Ziway area. Previous records indicated that at least 10 genera of assassin bugs have been recorded on various crops in Ethiopia (Abate, 1991).

Pheidole **sp. and an unidentified species (Hymenoptera: Formicidae)**
At least two species of ants were associated with stalk borers in sorghum and maize in Ethiopia. These were

usually found attacking larvae and pupae in mature stalks. Bonhof (1998) reported that *Pheidole* spp. attack eggs of stalk borers in several African countries. Sorghum plants containing ant colonies were observed at 39 of the 51 sites sampled (Fig. 2). Frequency of ant colonies was particularly high in Genbo Ber, Gedo Ber, Choriessa, Ejersa and Korga, where it ranged from 40 to 65%. In general, ant colonies were more common in sorghum than in maize.

Unidentified species (Coleoptera: Carabidae)
This dung beetle was recorded on *B. fusca* attacking maize in the Adulala area. Bonhof's (1998) review of predators does not mention carabid beetles attacking stalk borers of cereals in Africa.

***Diaperasticus erythrocephala* Olivier and an unidentified species (Dermaptera: Forficulidae), and unidentified species (Dermaptera: Labiduridae)**
D. erythrocephala and at least two unidentified species of earwigs associated with stalk borers of maize and sorghum were recorded during this study. *D. erythrocephala* was the most abundant species. It has a widespread distribution in Ethiopia. In maize, earwigs were observed in 15 of the 25 sites sampled. They were appreciably more abundant in maize than in sorghum. The maximum numbers of earwigs per 20 maize plants (55) were at Odaharo, in the Bako-Tibe area. Other areas where earwigs were abundant included Welenchiti (51), Adulala (27), Korga (25), and Bako (20). Bonhof (1998) reported *D. erythrocephala* and *Forficula auricularia* attacking eggs and larvae of *C. partellus* in Kenya.

***Chiracanthium* sp. Araneida: Clubionidae**
Unidentified species: Araneida: Gnophosidae
Unidentified species: Araneida: Thomisidae
Chiracanthium sp. was recorded on *B. fusca* attacking maize in the Ziway area. The other spiders were observed in the Melkasa and the Gambella areas. Spider numbers were relatively less abundant and they occurred relatively less frequently than earwigs and ants. Bonhof's (1998) review shows that some spiders may attack *C. partellus* eggs in Kenya while the majority of them are predaceous on larval stages of the African sugar cane borer, *Eldana saccharina* Walker, in South Africa.

Results of this study revealed that a large number of natural enemies, consisting of 10 larval parasitoids, 3 pupal parasitoids, 6 hyperparasitoids and 18 predators were associated with lepidopterous stalk borers of maize and sorghum in Ethiopia. Of particular significance was the high rate of parasitization by the native parasitoid *C. sesamiae* and the presence of its Asiatic relative, *C. flavipes*, which had been introduced into other parts of Africa for biological control of the spotted stalk borer, *C. partellus*. This information is significant for setting priorities for stalk borer management in Ethiopia. Presence of large numbers of species of parasitoids and predators suggested that there is a very high chance of success for biological control of stalk borers. Ingram (1983) reported that introduction and release of exotic parasitoids against cereal stalk borers has not been successful in western, eastern, or southern Africa. A better understanding of the natural enemy complex of stalk borers may allow development of strategies for conservation and enhancement of the effectiveness of native natural enemies of stalk borers. It is suggested that the use of timely planting, habitat management, and use of locally available materials (such as neem seed powder), as and when the need arises, may be exploited for the control of stalk borers in maize and sorghum in Ethiopia.

Effects of Neem Seed Powder on Stalk Borers

Even though there were significant differences among egg batch counts at different sowing dates, crop type, and crop growth stage, neem treatment did not have a significant effect on the number of egg batches.

Neem treatments were significantly superior to the untreated check in reducing leaf damage. Infestation levels increased progressively with the growth stages of the crop. Peak infestation was reached at 5–7 weeks in maize whereas it tended to continue increasing up to 8 weeks in sorghum. Infestation levels in maize were from 28% to 57% (avg. 46.4%) in 1997 and from 29% to 47% (avg. 40.9%) in 1998. It appeared that the onset of egg laying and leaf damage by *C. partellus* in maize was earlier than in sorghum. The extended period of damage in sorghum indicates extended egg laying by overlapping generations of *C. partellus*.

Neem treatments had highly significant effects on borer density at the three plant growth stages sampled. Two applications of neem seed powder (30 and 40 days after emergence) resulted in a significant ($P < 0.05$) reduction of stalk borers per plant at 8 weeks both in maize and sorghum during both years. Mean numbers of borers per 10 plants in one application were not significantly different from the untreated check in sorghum but superior to the check and inferior to two applications in maize during both years (Table 3).

Results at 10 weeks showed that both two and one application of neem seed powder were significantly superior to the untreated check (without significant difference between the two) in 1997 for sorghum,

Table 3. Stalk borers per 10 plants in maize and sorghum grown with and without neem seed powder treatment at Melkasa (1997 and 1998).

	Maize		Sorghum	
Treatment	1997	1998	1997	1998
		8 weeks after seedling emergence		
Treated (2×)	5.2c	3.8b	16.1b	10.9b
Treated (1×)	9.4b	5.5b	28.1a	16.8a
Untreated	16.5a	10.3a	24.8a	17.5a
		10 weeks after seedling emergence		
Treated (2×)	8.8b	7.5b	27.8b	23.9a
Treated (1×)	11.7b	8.0b	33.4b	26.8a
Untreated	21.7a	15.1a	44.1a	29.9a
		At harvest		
Treated (2×)	11.9b	8.0b	46.2b	41.0a
Treated (1×)	12.0ab	10.1ab	52.6a	41.6a
Untreated	17.5a	13.3a	49.4ab	44.1a

Means within a column (for each growth stage), followed by the same letters are not significantly different from each other at $P \leq 0.05$.

and both in 1997 and 1998 for maize. Both of the neem treatments showed better performance than the untreated check in sorghum in 1998, but the differences were not significant.

Furthermore, at harvest, two applications of neem resulted in significantly fewer mean numbers of borers per 10 plants in sorghum in 1997 and during both years in maize. One treatment was not significantly different from the untreated check. Differences among treatments in sorghum in 1998 were not statistically different (at harvest), even though neem treatments showed a slightly lower number of borers (Table 3).

It should be noted here that borer density was approximately doubled between 10 weeks and harvest in sorghum, whereas such differences were not observed in maize. This might be attributed to the extended egg laying and re-infestation by overlapping generations of *C. partellus* in sorghum. It is possible that the effects of neem treatments do not last long enough to influence borer numbers at harvest.

Neem treatment had a highly significant influence on percent pupation by *C. partellus* at the three crop growth stages sampled. There was no significant difference between mean percent pupation between 1997 and 1998. In contrast, the overall average percent pupation in maize (4.1%, 16.6% and 41.0%, respectively, at 8 and 10 weeks and harvest) was significantly greater than that in sorghum (1.6%, 8.4% and 24.9%, respectively, for 8 and 10 weeks and harvest).

In maize, the means for the untreated check showed significantly superior percent pupation compared to the means for the neem treatments (Table 4). Here, neem treatment applied twice showed the lowest level of pupation at all times of sampling. The means for one application were also comparable to two applications at 8 and 10 weeks. However, at harvest, the means for one application of neem were not significantly different from those of the untreated check (Table 4).

There were appreciable differences among treatment means for sorghum samples, particularly for 10 wae, both in 1997 and 1998; the highest pupation was in the untreated check whereas the lowest was in plots treated twice with neem (Table 4). However, none of the means were significantly different from each other. Similarly, even though neem treatment applied twice showed the lowest level of pupation compared to the mean for treated once and the untreated check at harvest, the differences were not significant.

The use of botanicals is an indigenous technology that has been practiced by many farmers in Ethiopia and elsewhere in Africa (Abate and Ampofo, 1996; Abate *et al.,* 2000). However, its use has been limited to either storage pests, as can be seen from many reports (Dejene, 2002) or small plots (such as garden crops), rather than field crops such as sorghum and maize. Particularly lacking are empirical data on application rates. Our results demonstrated that neem seed powder (mixed with pure, fine sand at a 1:1 ratio) and applied twice (at 30 and 45 days after emergence) at about 5 kg ha^{-1} reduced borer damage to sorghum and maize significantly. These results suggest that the use of neem would play an important role in the integrated management of cereal stalk borers in Ethiopia.

Work that remains to be done to popularize the use of neem in Ethiopia is making available adequate

Table 4. Percent pupation in *Chilo partellus* in maize and grown with and without neem seed powder treatment at Melkasa (1997 and 1998).

Treatment	Maize 1997	Maize 1998	Sorghum 1997	Sorghum 1998
		8 weeks after seedling emergence		
Treated (2×)	0.8b	0.4c	2.1a	0.9a
Treated (1×)	0.8b	5.2b	2.5a	0.4a
Untreated	6.6a	11.2a	2.9a	1.4a
		10 weeks after seedling emergence		
Treated (2×)	14.9b	7.8b	10.3a	1.1a
Treated (1×)	17.1b	11.3b	12.9a	5.5a
Untreated	34.5a	19.4a	14.6a	9.2a
		At harvest		
Treated (2×)	34.2b	32.6b	21.8a	24.3a
Treated (1×)	39.2ab	47.5a	26.3a	24.8a
Untreated	42.2a	50.3a	27.4a	24.6a

Means within a column (for each growth stage), followed by the same letters are not significantly different from each other at P ≤ 0.05.

supply and developing a more efficient delivery (application) mechanism. Currently, the neem tree is usually grown as a windbreak around farms or as an ornamental in towns in warmer parts of Ethiopia, such as Dire Dawa, Kobo and Gambella. Initiatives are needed to introduce planting this tree by farmers in sorghum growing areas where stalk borers are the major problem. The ability of the neem tree to thrive in moisture deficit areas and its multipurpose use as fuel wood, ornamental and insecticide would make it particularly attractive to farmers.

The current method of application (dropping a pinch in each whorl) is both time-consuming and wasteful, especially on a large-scale production. There is an urgent need for developing a device that could drop a measured amount of the powder in each whorl.

Table 5. Percent leaf damage by stalk borers in maize sown at different dates and grown with and without insecticide treatments.

Treatment	Melkasa 1997	Melkasa 1998	Hawassa 1997	Arsi-Negele 1997
Sowing date (main plots)				
1st	7.0a	5.9a	5.2ab	20.9a
2nd	10.0a	4.7a	5.3ab	6.1b
3rd	10.7a	9.0a	3.9b	4.5b
4th	9.2a	11.6a	5.7ab	3.7b
Insecticide treatments (subplots)				
Applied 2×	5.1b	7.5a	1.8a	4.6b
Applied 1×	5.7b	7.2a	6.8a	10.0ab
Untreated	16.9a	8.8a	6.5a	11.9a
Mean	9.2 ± 1.5	7.8 ± 1.0	5.0 ± 0.9	8.8 ± 2.1
CV (%)	49.8	80.3	95.8	69.3

Means within a column (for each growth stage), followed by the same letters are not significantly different from each other at P ≤ 0.05. CV = coefficient of variance.

Effects of Sowing Date and Insecticide Treatments

Differences in percent leaf damage among sowing date treatments at Melkasa were non-significant both in 1997 and 1998. In contrast, highly significant differences were observed at Hawassa and Arsi-Negele (Table 5). It is interesting to note that the first sown plots at Arsi-Negele suffered significantly greater (P<0.01) level of leaf damage than the other sowing dates.

Differences in insecticide treatments were significant (P<0.05) at Melkasa and Arsi-Negele in the 1997 crop season whereas they were non-significant in 1998 at Melkasa and in 1997 at Hawassa (Table 5). Both single and double applications were superior to the untreated check.

Differences in the mean number of stalk borers per 10 plants were non-significant at Melkasa in 1997 but significant (P<0.05) in 1998 and in 1997 at Hawassa (Table 6). The mean number of borers at Melkasa was highest in first sown plots but the reverse was true for Hawassa. Both single and double applications of insecticide were superior to the untreated check during both years at Melkasa but non-significant at Hawassa (Table 6).

Differences among grain yield means were highly significant for sowing dates at all locations during both years (Table 7). The second sowing date was significantly superior to other sowing dates at all locations.

Insecticides applied twice were significantly superior to the untreated check at Melkasa in 1998 and both at Hawassa and Arsi-Negele. Differences between two and one application were non-significant at Melkasa during the 1997 season even though they were superior to the untreated check (Table 7).

These results suggest that grain yield losses due to stalk borers at Melkasa range between 12.8% and 18.3% whereas the losses at Hawassa and Arsi-Negele stand at approximately 22% and 92.3%, respectively.

Table 6. Mean numbers of stalk borers per 10 plants in maize sown at different dates and grown with and without insecticide treatments.

Treatment	Melkasa 1997	Melkasa 1998	Hawassa 1997	Arsi-Negele 1997
Sowing date (main plots)				
1st	7.5a	10.7ab	2.3b	NA
2nd	8.8a	4.0ab	1.4b	NA
3rd	11.0a	2.2b	6.7ab	NA
4th	9.5a	4.0ab	11.4a	NA
Insecticide treatments (subplots)				
Applied 2×	1.9b	3.7ab	3.9a	NA
Applied 1×	4.3b	3.0b	5.2a	NA
Untreated	21.5a	8.9a	7.3a	NA
Mean	9.2 ± 2.29	5.2 ± 1.21	5.4 ± 1.16	NA
CV (%)	86.2	86.0	79.7	NA

Means within a column (for each growth stage), followed by the same letters are not significantly different from each other at P ≤ 0.05. CV = coefficient of variance. CV = coefficient of variance.

Table 7. Grain yield (t ha^{-1}) in maize sown at different dates and grown with and without insecticide treatments.

Treatment	Melkasa 1997	Melkasa 1998	Hawassa 1997	Arsi-Negele 1997
Sowing date (main plots)				
1st	1.9a	1.6c	3.2ab	2.2b
2nd	2.0a	2.2a	3.7a	3.7a
3rd	1.8a	1.9ab	2.8ab	1.9b
4th	1.3b	1.8bc	2.4b	2.2b
Insecticide treatments (subplots)				
Applied 2×	1.7ab	2.0a	2.4a	3.7a
Applied 1×	1.9a	1.9ab	2.8b	2.2b
Untreated	1.6b	1.8b	2.8b	1.9b
Mean	1.8	1.9	3.0	2.5
CV (%)	0.6	0.3	0.9	1.2

Means within a column (for each growth stage), followed by the same letters are not significantly different from each other at P ≤ 0.05. CV = coefficient of variance. CV = coefficient of variance.

Summary

Three species of stalk borers (*B. fusca, C. partellus* and *S. calamistis*) were widely distributed across maize and sorghum growing areas of Ethiopia. However, their relative abundance and significance varied substantially across locations. *B. fusca* was found between 500 masl and 2,450 masl whereas *C. partellus* was recorded at altitudes of 500–2,180 masl. However, it does not necessarily follow that *B. fusca* is important at higher altitudes and *C. partellus* at lower altitudes. Grain yield losses due to stalk borers in maize may range from approximately 13–18% at Melkasa to 22% at Hawassa and more than 91% at Arsi-Negele.

It was established that a large number of natural enemies are associated with the cereal stalk borers in Ethiopia. *C. sesamiae* was found to be the most abundant and geographically widely distributed larval parasitoid. The level of parasitism was influenced by location and crop, with the average parasitization rates of approximately 43% in sorghum and 25% in maize. *P. furvus*, followed by *S. rufus*, and *D. busseolae* were the most important pupal parasitoids. Among the predators recorded, earwig, *D. erythrocephala,* and an unidentified species of ant were most abundant and widely distributed in Ethiopia.

A better understanding of the natural enemy complex is important for developing strategies for integrated pest management (IPM) of stalk borers. Our results suggest that the use of timely planting, habitat management, and use of locally available materials, when the need arises, may also be given priority, in addition to biological control, for the integrated pest management (IPM) of stalk borers. Extended use of neem seed powder for the control of stalk borers under small-scale production systems is an exciting finding but this has to be scaled up in the coming years. There is a compelling need for introducing neem tree planting by farmers and improving the application techniques of the seed powder in areas where the pests cause significant yield loss.

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Review of the Past Decade's (2001–2011) Research on Post-Harvest Insect Pests of Maize in Ethiopia

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Introduction

After development of improved high yielding maize varieties, production of maize in Ethiopia has increased by nearly three-fold. This spectacular increase is much greater than that observed in any other crop. The rapid expansion of the production of these high yielding varieties and their dissemination throughout the country has led to many cases of 'switch-over' from traditionally grown cultivars to improved maize varieties. Despite these marvelous achievements, there is still food insecurity in the country due to various reasons.

Among other things, food security is greatly threatened by excessive post-harvest losses caused by stored product insect pests, under small holder on-farm situations and at a country level, predominantly caused by the maize weevil and Angoumois grain moth. Estimations based on some limited observations indicated that grain losses in maize due to storage insect pests alone are about 30–100% (Abraham 2003; Girma, 2006). Analysis of food aid, food import, and food security figures versus post-harvest losses suggested that addressing storage losses could have a significant impact on food security and farm-income without increasing pressure on the land (Abraham *et al*., 2008). Storing maize grain is not only an activity to conserve food but a financial investment. In Ethiopia, maize sold six months after harvest, when grain is relatively scarce, generally commands a much higher price than maize sold at the time of harvest, when maize and other foods are plentiful.

The importance of post-harvest losses in developing countries has been recognized worldwide since 1975 when the United Nations General Assembly passed a resolution committing member states to reduce post-harvest food losses by 50% by 1985 (Harris and Lindblad, 1978). In Ethiopia, there was no research work on stored product pest management (except a few preliminary studies) until the late 1980s when some graduate students took the problem as their thesis research topics. Since then several areas of research have been covered by different institutions and a lot of information has been compiled on a series of crop protection and national maize workshop proceedings. Therefore, the objective of this paper is to summarize the results of research on post-harvest insect pests of maize since 2001 and some other research findings that were not reported during the Second National Maize Workshop. Future research directions are also explicitly indicated.

Survey of Arthropod Pests in Stored Maize

Over the years, more than 30 species of arthropods associated with stored grains have been recorded in Ethiopia. Out of these, only a dozen species are known to be of major importance. A few of them were unusual arthropods in storage and could not be identified (e.g., two rare genera of Pseudoscorpions; Abraham, 2003). Certain species recorded as uncommon might be important in particular conditions of storage and/or in the presence of the major primary pest species. The most common insect pests of stored maize in all maize growing areas were *Sitophilus zeamais* (maize weevil), *Sitotroga cerealella* (Angoumois grain moth), *Ephestia cautella* (tropical warehouse moth), *Plodia interpunctella* (Indian meal moth), *Tribolium* spp. (flour beetles), *Cryptolestes* spp. and *Carpophilus* spp. Several species of parasitic wasps were also recorded of which *Anisopteromalus calandrae* (Howard) and *Choetospila elegans* (Westwood) were the most common. In addition to parasitoids, several predatory reduvid and anthocorid (*Xylocoris* spp.) bugs were recorded in low numbers (Abraham, 2003). .

Furthermore, the larger grain borer (LGB) (*Prostephanus truncates* (Horn)), which is known to be the most devastating storage pest of maize in Kenya, was recorded as quarantine pest in April 2008 at Moyale Plant Quarantine Station (Abebe and Hiwot, 2009). Since then adult beetles of LGB have been continuously trapped in certain months. It is doubtless that once it is introduced, the opportunity for this insect to become permanently established in the country is greater. Therefore, this harmful guest to our country has given a further assignment to the Ethiopian government, researchers, extension workers and farmers.

Management methods

Cultural control

Among various cultural methods tested at the Bako Research Center, solar heating of maize grain placed on a black polyethylene sheet, and covered with a translucent plastic sheet for at least five sunny days caused significantly high (about 72%) mortality of maize weevil (Abraham, 2003). Moreover, oven heating, a simulation of farmers' practice of warming batches of grain over the heat of fire was significantly superior to the untreated check in controlling maize weevil. A solar heating study was carried out by the Ambo Plant Protection Research Center (APPRC) entomology department to assess the effectiveness of simple solar absorbance beds, built from local materials, to control maize weevils, *Sitophilus zeamais* (Motsch.) in infested maize. The solar heat absorbance beds made from the foam and grass straw have raised the temperature by 28^{o}C from the normal ambient temperature, which was sufficient enough to control different weevils. One hundred percent mortality was recorded on maize weevil at temperatures of 55–60^{o}C within two to three hours exposure time. It is also a low input technology and environmentally friendly (APPRC, 2010). On the other hand, the study conducted at Melkasa indicated that repairing and thorough cleaning of storage containers before filling with grain alone kept the grain for a longer time in the traditional experimental stores (Abraham, 2003).

Botanical control

The utilization of plant materials to protect field and stored commodities against insect attack has a long history. Many of the plant species concerned have also been used in traditional medicine by local communities and have been collected from the field or specifically cultivated for these purposes. Leaves, roots, twigs and flowers have been admixed with various commodities as protectants in different parts of the world, particularly in India, China and Africa (Golob and Webley, 1980).

In Ethiopia several studies were carried out to screen effective botanicals for the control of the maize weevil, *S. zeamais.* Among the botanicals, outstanding ones were Mexican tea powder (*Chenopodium umbrosiodes* L.), triplex and neem seed powder (*Azadirchata indica*) which performed very well and resulted in high percent adult mortality, reduced progeny emergence and low percent grain damage (Firdissa and Abraham, 1999; Girma, 2006; Girma *et al.,* 2008d). In rate determination studies, Mekuria (1995) reported that *C. umbrosiodes* applied at the rate of 2% and 4% weight for weight (w/w) powder is very effective against the maize weevil, while Girma (2006) found that *C. umbrosiodes* applied at the rate of 1.25% w/w powder gave comparable results to the standard insecticide pirimiphose-methyl. Similarly, treatment of maize grain with dry seed powder of endod (*Pytolacta dodcandra*) caused a high level of mortality (61–93%) and a lower level of progeny emergence of maize weevil (EARO, 1999). Likewise, treatment of maize grain with Triplex (soap factory by-product of *P. dodcandra* (endod)) at the rate of 0.1% and 0.25% w/w caused a high percentage weevil mortality (90–100%) (Girma, 2006; Girma *et al.,* 2008a). Other botanicals that give good control at the rate of 10% w/w included *Croton macrostachus, Ricinus communis, Datura stramonium, Capsicum frutescens* and *Millia azadricta* (Emana, 1999). The results of the three most outstanding botanicals are shown in Table 1.

Use of inert materials

The use of chemically inert materials, such as ashes, sand or other minerals, powders or seeds in large quantities, to fill up the interstitial space in grain bulks and to pose a barrier to insect movement is quite widespread. The abrasive nature of such materials may also help to control infestation by damaging the insect cuticle leading to dehydration and death. Several studies at Bako confirmed that the various inert materials evaluated are effective in protecting maize grain from maize weevil. Silicosec at 0.1% w/w, filter cake (melkabam) at 1% w/w, wood ash at 2.5–10% w/w (Girma 2006; Girma *et al.,* 2008b) (Table 2) and sand at 30% (for short term storage) and 70% (for long-term storage) (Abraham, 2003) could be suggested for use as an alternative maize weevil management option. Moreover, *tef* (*Eragrotis tef*) at 30 to 50% may provide adequate protection for short-term storage; however, for long-term storage the rate should not be less than 70% (Abraham, 2003).

Use of resistant varieties

Resistant varieties are among the most important component of an integrated pest management system. Various maize genotypes, including hybrids, composites and lines at different breeding stages, were evaluated for resistance to the maize weevil in no-choice tests in the laboratory at Bako between 1989 and 1991, and 1996 and 1998. The results indicated that many of the maize genotypes, including AW8047, INT-A, Pob-62TLWF-QPM, TUXEPENO C6, UCB, Golden Valley, etc. were identified to be relatively resistant to the maize weevil (Abraham, 1991; Firdissa *et al*., 2001).

In the study conducted at Haramaya, Dejene (1984) observed variations in the number of progeny weevils dead and alive among 16 experimental varieties of maize. Abraham (1991) evaluated 25 maize genotypes for resistance to the maize weevil in the laboratory at Bako and noted significant differences among the genotypes. Thus, the study suggested the possibility of finding useful levels of resistance within the maize genotypes. In another study, commercial varieties of maize showed a wide variation in response to the maize weevil. UCB followed by A511, which were found relatively resistant, had very few progeny emergence with the least grain damages of 0.3% and 8.3%, respectively. BH140 was highly damaged by the weevils having 84% and 25.7% progeny emergence and grain damage records, respectively (Demissew *et al*., 2004).

In the study conducted at Hawassa, UCB, H8151 and H501 in free choice test and H8151 and H501 in no-choice test were found to be resistant to the Angoumois grain moth (Emana, 1993; Emana and Assefa, 1995).

Table 1. Main effects (±SE) of botanicals (neem seed powder, mexican tea powder, and triplex) and their rates on percent mortality of adult maize weevil 3, 7, 15, 21 and 28 days after exposure.

Main effect	Botanicals/rate (% w/w of grain)								
	Neem seed powder rate			Mexican tea powder rate			Triplex rate		
	0.5	1	2	1.25	2.5	5	0.1	0.2	0.4
	3 days after exposure								
Rate	4.4±2.9b	11.3±3.3c	21.6±4.7c	100a	100a	100a	85.4±5.5b	92.2±2.3b	93.3±1.1b
botanicals		12.4±2.7c				100a		90.3±1.6b	
	7 days after exposure								
Rate	9.8±77.4d	40.2±11.5c	68.7±6.4b	–	–	–	96.21±0.78a	99.13±0.5a	99.77±1.26a
botanicals		39.6±6.4b			–			98.4±0.8a	
	15 days after exposure								
Rate	18.4±4.3d	56.8±8.4c	85.1±10.8b	–	–	–	100a	100a	100a
botanicals		53.4±6.4b			–			100a	
	21 days after exposure								
Rate	25.8±9.2d	64.7±9.2c	91.3±6.3b	–	–	–	–	–	–
botanicals		60.6±6.04			–			–	
	28 days after exposure								
Rate	33.6±3.5d	69.8±7.5c	94.8±4.2b	–	–	–	–	–	–
botanicals		66.1±5.8			–			–	

Source: Girma (2006) and Girma *et al.* (2008d). Means with the same letter in a row are not statistically significant at $P \leq 0.05$, '–' = data not available as all treated insects died.

Table 2. Main effects (±SE) of inert dust (silicosec, filter cake, and wood ash) and their rates on percent mortality of adult maize weevil 3, 7 and 15 days after exposure.

Main effect	Inert dust/rate (% w/w of grain)								
	Silicosec rates			Filter cake rates			Wood ash rates		
	0.05	0.1	0.2	1.0	2.5	5.0	2.5	5.0	10
	3 days after exposure								
Rate	98.8±1.3a	99.1±0.4a	99.5±0.9a	87.4±2.4cd	92.3±7.8bc	97.8±7.5ab	65.0±6.9f	73.2±12.7ef	79.6±5.5de
Inert dust		99.1±0.43a			92.5±1.6b				72.6±3.3c
	7 days after exposure								
Rate	99.4a	100a	100a	95.8±0.7ab	98.5±1.3ab	99.6±4.2a	84.7±6.6c	89.0±8.0c	93.7±5.2c
Inert dust		99.8a			97.9±0.6b			89.1±1.6c	
	15 days after exposure								
Rate	100	–	–	100a	100a	100a	97.6±1.1b	99.3±2.0ab	99.3±0.7ab
Inert dust		100			100a			8.7±0.4b	

Source: Girma (2006) and Girma *et al.* (2008b). Means with the same letter in a row are not statistically significant at $P \leq 0.05$.
'–' = data not available as all treated insects died.

Forty maize genotypes were screened for weevil resistance at Bako and it was found that there was great variability in weevil resistance among genotypes that could be exploited in a suitable breeding procedure to develop acceptable resistance. The inheritance study of five introduced weevil resistance inbred lines and three testers using Line × Tester analysis for resistance to maize weevil at Bako indicated that the proportional contribution of the general combining ability (GCA) of lines outweighed that of testers unlike for agronomic traits in which the opposite was true (Demissew, 2004). In the consecutive work carried out at Bako, SZSYNA99-F2-33-4-1, SZSYNA99-F2-79-4-3 and their crosses with the testers; SZSYNA99-F2-79-4-3/CML197 and CML197/SZSYNA99-F2-33-4-1, SZSYNA99-F_2-33-4-2/SC22 were found to be resistant (Girma *et al*., 2008c). Concurrently, based on pre-harvest studies of weevil infestation, grain texture (flint or dent) was not the only factor responsible for weevil resistance (Girma, 2006; Girma *et al*., 2008c). It is concluded that besides grain texture, husk tip extension and husk tightness were the two most important characters conferring resistance to maize ears against the maize weevil in the field.

Since 2009 several storage pest resistant maize varieties have been introduced from Kenya (IRMA II project) to test their local adaptability and resistance to maize weevil. From these introduced materials best performing and tolerant varieties were identified for further location testing (BNMRP, 2010). Parental lines for selected varieties have been also introduced to test their adaptability and resistance. In general, research on varietal resistance against storage pests has given encouraging results.

Entomopathogenic fungi

Pathogenicity of five different isolates of *Beauveria bassiana* and *Metharizium anisophilae* each at four different concentrations (1×10^5, 10^6, 10^7 and 10^8 conidia ml^{-1}) were tested in 2007 at Bako in collaboration with APPRC. The result indicated that there was significant difference among the isolates and rates in mortality and survival time. Based on average mortality and median survival time, isolates PPRC-GG at 10^8 and PPRC-HH at 10^8 resulted in the highest mortality and list median survival time (BNMRP, 2007). Based on preliminary results, Addis (2008) conducted a series of laboratory experiments to determine the virulence of 17 isolates comprising 11 *Metarhizium anisopliae* and 6 *Beauveria bassiana* against the maize weevil, *S. zeamais*. Dose response was assessed for the three most virulent *M. anisopliae* isolates with five ten-fold doses ranging from 1×10^4 to 1×10^8 conidia ml^{-1}. The effect of exposure methods was also determined with the two isolates, PPRC-2 and PPRC-51. Moreover, PPRC-2 grown over different cereal grain substrates (cracked wheat, sorghum, cracked maize and rice) was evaluated against maize weevil. The results showed that all tested isolates at a concentration of 1×10^8 conidia ml^{-1} were capable of infecting the maize weevil, but their virulence determined by adult mortality and LT50 varied from 13.4 to 98.3% and 3.9 to 31.0 days, respectively. Finally a total of five isolates, three from *M. anisopliae* (PPRC-2, PPRC-14, PPRC-51), and two from *B. bassiana* (PPRC-HH and PPRC-GG) were identified as the most virulent isolates (Addis, 2008).

Use of botanical oils

The application of oils of botanical origin (vegetable oils) for protection from storage insect pests has been confirmed as effective by many workers. These oils rapidly produced adult mortality and prevented F_1 emergence. In addition to action against adult insects, vegetable oils are generally reported to exert ovicidal action (Don-Pedro, 1989). The main concerns over the use of oils, however, are the availability and price.

In Ethiopia, several experiments were carried out under laboratory conditions. In general, the results indicated that application of plant oils at 2.5–10 ml kg^{-1} can provide adequate protection, although the rate of adult mortality in the lower rate is gradual, and the higher rate impairs seed germination (Abraham, 2003). Girma *et al*. (2008a) verified the efficacy of some promising cooking oils *viz.*, noug oil, soybean oil, sunflower oil, corn oil and olive oil, against maize weevil, *S. zeamais*, in stored maize grain under local storage conditions at Bako. The results showed that all the cooking oils tested at the rate of 5 ml kg^{-1} had a significant toxic effect on the weevils in stored grains (Girma *et al*., 2008a). The cooking oil treatments significantly reduced weight loss and grain damage as compared with the untreated control. However, it is unlikely that oils alone would solve the problem of storage pests. These promising oils would, therefore, be very useful as components of integrated storage pest management in reducing post-harvest losses experienced by resource poor farmers, particularly for grains held for local consumption.

Hermetic storage/modified atmosphere

Among the various methods investigated, the use of hermetic/modified atmosphere storage to create a lethal or deleterious environment for the insects found in the stored grain has given promising results (Paster *et al*., 1991). These methods create a low oxygen modified atmosphere which normally results in 100% insect mortality of all life stages in a few days to 2 weeks as well as preventing mold development, protecting quality and preventing losses in the commodity (Philippe *et al*., 2006). It also prevents development of cancer causing mycotoxins and maintains the moisture level of the commodity regardless of ambient exterior humidity. In the case of seeds, maintaining seed germination percentage and vigor is the dominant consideration (De Bruin, 2005).

The study conducted on the evaluation of modern organic hermetic storage cocoon at Bako indicated that after 6 months of storage the insects present in the grains during initial storage were all dead and no re-infestation was recorded. In addition, the grains remained identical in appearance and preserved their germination potential (Table 3) (Girma, 2008). The oxygen levels typically went down to 3.2% in a month (Fig. 1). The O_2 levels persisted in the cocoon for an additional one month, after which it increased gradually. After 6 months of the treatment, the O_2 content in the cocoon was 5.68%, which was still lethal to the insects (Girma, 2008).

Regarding modified atmosphere, significant variations were observed among gases produced from different organic matters degradation (cow dung, sugar cane and maize stover), standard check, and untreated check (Table 4). Significantly higher dead weevils, lower damaged grain and weight loss were observed in the organic degradations of sugar cane, cow dung and maize stover than the untreated check (Table 4). From the biological degradation of organic matter it was concluded that the gas produced from biological digestion of cow dung, sugar cane and maize stover can be used as a control option for maize storage pest in airtight storage. The period of protection lasted for about 10 months.

Chemical control

Conventional insecticides, as dust formulations which are admixed with the commodity, are safe and effective, providing that only those chemicals that have a label recommendation for use on stored grains are used (such as pirimiphos-methyl [Actellic: 2%],

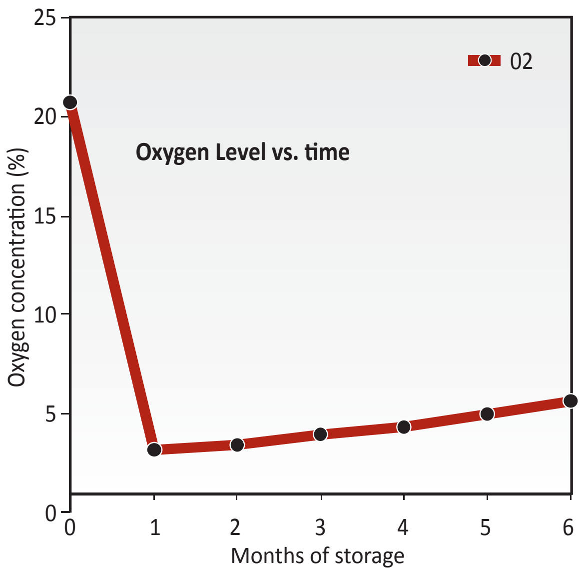

Figure 1. Average O_2 concentration (%) in the GrainPro Cocoon containing 4.9 t of maize grain.

Source: Girma (2008).

Table 3. Mean number of live insects, percentage germination and moisture content at the start and end of experiment.

Treatment	Length of trial period (days)	Initial germination (%)	Germination potential at end of trial	Initial moisture content (%)	Moisture content at end of trial (%)	Live weevils at start of trial (kg)	Live weevils at end of trial (kg)
Cocoon™	180	96.5	98.4a	10.4a	10.1a	2.3a	0.0b
Actellic 2% dust	180	96.5	99.2a	10.5a	10.2a	2.3a	0.0b
Untreated	180	96.5	93.7b	10.5a	10.3a	3.0a	88.0a
CV (%)			2.0	1.8	3.6	32.0	19.7

Means with the same letter in a row are not statistically significant at $P \le 0.05$. CV = coefficient of variance.

Table 4. The effects of modified atmosphere on percentages of weevil mortality, damaged grain and grain weight losses after 12 weeks of storage.

	Percent			
Treatment	Dead weevils	Damaged grain	Grain weight loss	Seed germination
Cow Dung	78.0b	0.9c	0.5c	96.2a
Sugar cane	79.4b	0.4c	0.3c	96.2a
Maize stover	82.7b	0.8c	0.2c	97.0a
Quick phose	98.5a	0.2e	0.2c	97.0a
Plastic sealed	54.0c	9.2b	2.4b	96.0a
Untreated check	17.0d	19.2a	4.5a	97.0a
CV%	3.1	4.0	32.1	2.4

Source: Tadesse *et al.* (2011). Values in the same column followed by the same letters are not significantly different from each other at $P \le 0.05$.

and malathion), and proper attention is paid toward user safety aspects. In many developing countries including Ethiopia, availability of suitable products is poor, and often inappropriate, dangerous chemicals, such as lindane and DDT, may be used instead. The direct application of a pesticide to a food commodity, known as 'admixture', will always produce a residue which will be more or less persistent depending upon the chemical nature of the pesticide used. This may, however, create a potential hazard or, at least, a source of possible anxiety to the user of the commodity. The use of the fumigant gas aluminum phosphide (phosphine) at the farm level is becoming increasingly more common where it is available to farmers. This trend is a matter of some concern as farmers are rarely sufficiently trained in the safe handling and use of such products and its misuse is likely to lead to accidental poisoning. Its use is to be discouraged where possible although if its use continues to spread it may be necessary to ensure that extension workers are sufficiently knowledgeable and trained in the application of the fumigant to be able to train farmers in its safe use and handling.

Several verification tests of different fumigants for the control of stored maize grain insect pests were carried out at Bako under air-tight storage conditions. The results showed that Degesch plate/strip, Agroxin 56 TB, Shenphos and BIOALPHOS provided complete protection against maize weevil as equally effective as the standard fumigant (Table 7) (Girma, 2010). All the fumigants caused 100% weevil mortality for about 5–6 months except Agroxin 56 TB. Lithopose was also recommended as an effective fumigant for the control of maize weevil. As phosphine gases which are released from fumigants are considered toxic to human beings, proper safety precautions need to be followed during its usage. The grain must be placed in an air-tight container in order to prevent escape of the fumes, i.e., users must have air-tight storage to conduct a thorough fumigation.

Table 5. Effect of niger seed oil and malathion dust combinations at different rates on the mortality of adult weevils.

Noug oil (5 ml kg^{-1}) (NO)	Malathion 5% D (50 g 0.5 t^{-1}) (MTD)	Percent weevils mortality			
		2 dai	4 dai	6 dai	12 dai
T_1= 0% (0 ml)	+ 100% (0.1 g)	26.0(17.0) ± 1.2 ^{a}	74.0(59.4) ± 1.2 ^{a}	100.0(89.5) ± 0.0 ^{a}	100.0(89.5) ± 0.0 ^{a}
T_2= 10% (0.1 ml)	+ 50% (0.05 g)	20.7(15.0) ± 0.7 ^{b}	32.7(34.9) ± 0.7 ^{b}	48.0(43.9) ± 1.2 ^{c}	100.0(89.5) ± 0.0 ^{a}
T_3= 20% (0.2 ml)	+ 40% (0.04 g)	19.3(14.5) ± 0.7 ^{b}	30.7(33.7) ± 0.7 ^{b}	50.0(45.0) ± 1.2 ^{c}	100.0(89.5) ± 0.0 ^{a}
T_4= 30% (0.3 ml)	+ 30% (0.03 g)	16.0(13.1) ± 0.0 ^{c}	20.0(26.6) ± 1.2 ^{c}	64.0(53.2) ± 1.2 ^{b}	100.0(89.5) ± 0.0 ^{a}
T_5= 40% (0.4 ml)	+ 20% (0.02 g)	16.0(13.1) ± 2.0 ^{c}	18.0(25.1) ± 1.2 ^{c}	66.0(54.4) ± 2.3 ^{b}	100.0(89.5) ± 0.0 ^{a}
T_6=50% (0.5 ml)	+ 10% (0.01 g)	16.0(13.1) ± 1.2 ^{c}	19.0(26.1) ± 1.8 ^{c}	64.0(53.6) ± 1.8 ^{b}	100.0(89.5) ± 0.0 ^{a}
T_7= 100% (1 ml)	+ 0% (0 g)	24.0(16.3) ± 1.2 ^{a}	76.0(60.7) ± 1.2 ^{a}	100.0(89.5) ± 0.0 ^{a}	100.0(89.5) ± 0.0 ^{a}
T_8 = Untreated check		0.0(0.4) ± 0.0 ^{d}	0.0(0.4) ± 0.0 ^{d}	2.7 (7.6) ± 1.8 ^{d}	6.0(14.1) ± 1.2 ^{b}
CV%		5.4	3.7	4.2	1.0

Source: Ahmed (2007). Means followed by the same letter within a column are not significantly different from each other at P ≤ 0.05 (Student-Newman-Keul`s Range Test). ANOVA was conducted on transformed values. dai = days after infestation, T = treatment, D = dust, T = treatment, CV = coefficient of variance. The values in the parentheses are angular transformed.

Table 6. Effect of different rates of malathion 5% D and Mexican tea powder combinations on weevil mortality.

Treatment	Percent weevils mortality			
	2 dai	4 dai	6 dai	12 dai
T_1	26.0(30.6) ± 3.1 ^{b}	74.0(59.4) ± 3.1 ^{a}	100.0(89.5) ± 0.0 ^{a}	100.0(89.5) ± 0.0 ^{a}
T_2	26.0(30.6) ± 2.0 ^{b}	30.0(33.6) ± 3.5 ^{c}	43.3(41.2) ± 4.4 ^{b}	100.0(89.5) ± 0.0 ^{a}
T_3	19.3(26.1) ± 0.7 ^{c}	30.0(33.6) ± 0.0 ^{c}	50.7(45.4) ± 0.7 ^{b}	100.0(89.5) ± 0.0 ^{a}
T_4	21.3(27.4) ± 3.5 ^{bc}	36.0(36.9) ± 1.2 ^{c}	42.7(40.8) ± 2.4 ^{b}	100.0(89.5) ± 0.0 ^{a}
T_5	46.0(42.7) ± 1.2 ^{a}	54.0(47.3) ± 1.2 ^{b}	100.0(89.5) ± 0.0 ^{a}	100.0(89.5) ± 0.0 ^{a}
T_6	48.7(44.3) ± 0.7 ^{a}	51.3(45.8) ± 0.7 ^{b}	100.0(89.5) ± 0.0 ^{a}	100.0(89.5) ± 0.0 ^{a}
T_7	24.7(29.6) ± 4.4 ^{bc}	75.3(60.5) ± 4.4 ^{a}	100.0(89.5)± 0.0 ^{a}	100.0(89.5) ± 0.0 ^{a}
T_8	0.0(0.4) ± 0.0 ^{d}	0.0(0.4) ± 0.0 ^{d}	1.3(4.1) ± 1.3 ^{c}	3.0(9.3) ± 0.7 ^{b}
CV %	8.7	5.4	4.3	0.8

Source: Ahmed (2007). Means followed by the same letter within a column are not significantly different from each other at P ≤ 0.05 (Student-Newman-Keul`s Range Test). ANOVA was conducted on transformed values. dai = days after infestation. The values in parentheses are angular transformed.

Table 7. Effect of different fumigants on maize weevil mortality, grain damage level, grain weight loss and maize grain germination after 6 months' storage.

Treatment	Weevil mortality (%)	Grain damage (%)	Weight loss (%)	Germination (%)
Degesch plate	100.0a	2.2b	0.1b	97.8a
Degesch strip	100.0a	0.8b	0.1b	97.8a
Agroxin 56 TB	84.5a	1.8b	0.2b	87.8a
Shenphos	100.0a	1.3b	0.1b	90.0a
BIOALPHOS	100.0a	5.4b	0.6b	94.4a
Phostoxin	100.0a	2.0b	0.0b	93.3a
Untreated	15.9b	19.5a	5.6a	73.3b
CV (%)	10.7	17.8	20.17	7.7

Means within a column followed by the same letter are not significantly different at $P \leq 0.05$. CV = coefficient of variance.

Integrated pest management (IPM)
According to the preliminary studies conducted at Bako, the combined use of weevil tolerant varieties with minimum rates of chenopodium plant powder, botanical triplex, silicosec, and filter cakes has reduced grain damage and thus was recommended for maize weevil management (Girma, 2006). Another study was conducted at Bako on combinations of different rates of niger seed oil and malathion dust and Mexican tea powder and malathion in terms of weevil mortality (Tables 5 and 6). All combinations of malathion dust and niger seed oil provided significant protection to maize from the maize weevil following 90 days after infestation (Ahmed, 2007). Following 156 days after infestation, malathion dust at 40% and 50% combined with niger oil at 20% and 10%, respectively, effectively controlled the maize weevil. The period of protection lasted for about 5 months in the laboratory. Seed germination was affected in the highest (uncombined) rate of niger seed oil.

Conclusion and Future Research Directions

Promising and/or recommendable results have been obtained since 2001. Certain recommended biopesticides need further commercialization. There are also some areas which did not get the attention they deserve. For example, IPM is the most sustainable method of pest control both in the field and in storage. However, it has received hardly any attention to date. Some important studies have been initiated in the past that need to be continued in the future. Screening of resistant varieties and searching for effective bio-control agents are some of the works underway. But considering the magnitude of insect pest problems and the amount of research work done so far it appears that post-harvest research in Ethiopia is in its infant stage. In this respect, the following points were suggested as future directions:

- Development of research capabilities in terms of training entomologists and establishing facilities for entomological research is mandatory.
- Genetic variation for storage pest resistance in maize has long been recognized and selected by farmers in different regions. If researchers in the public and private sectors are to meet the demands for maize in the future, the importance of grain storage within the breeding program must be recognized and incorporated.
- Biological control is often an underutilized component of IPM of stored grains. Therefore, for the development of a microbial control program, the recent works on screening of virulent isolates against the maize weevil should continue towards characterization, mass production, formulation and commercialization.
- The various research results and technologies from the research system will be worth nothing unless they are channeled to the farmers through extensive participatory demonstration and evaluation. Hence, the project will continue to verify improved post-harvest technologies.
- The application of a single control strategy to specific pests is hazardous due to the development of resistance. Hence, integration of different control options in a systematic manner within the social, economic and technical means of the farmers is worth recommending. Thus, future research and technology development activities should target the testing of management strategies in an integrated way that farmers can access safely.
- Country-wide well-coordinated and periodic surveys will be needed. Special attention should be given to the frequent assessment of LGB.
- Strong collaboration between maize entomologists and breeders will lead to fruitful results.

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Maize Pathology Research in Ethiopia in the 2000s: A Review

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Introduction

Maize is widely grown in Ethiopia in diverse agro-climatic conditions. It is one of the most important strategic crops selected for food security mainly due to its high productivity and wider adaptability. Maize is the second most important cereal crops after *tef* in area coverage. In 2007, it was produced on 2.1 million ha of land which covers about 21.7% of all the land allotted to cereals production (CSA, 2010). Although improved cultivars have been included in the national extension package, the national average yield of maize is only 2.3 t ha^{-1} (CSA, 2010). The low yield is attributed to a combination of several constraints among which diseases play a major role.

Since the start of pathology research in Ethiopia in early 1950s, various research activities on maize disease have been carried out, and the results have been documented over the years (Assefa and Tewabech, 1993; Tewabech *et al*., 2002). The major diseases identified/recognized are gray leaf spot (GLS) caused by *Cercospora zeae-maydis*, *turcicum* leaf blight (TLB) caused by *Exserohilum turcicum* (Pass.), common leaf rust (CLR) caused by *Puccinia sorghi* Schw and maize streak virus (MSV). Apart from foliar diseases, maize suffers from different ear/kernel, stalk and storage diseases caused by various fungi. Ear and kernel rots (*Fusarium* and *Gibberella* spp.) and storage diseases (*Fusarium* spp., *Penicullim* spp. and *Aspergillus* spp.) are some of the important diseases caused by fungi.

Disease incidence is sporadic and sometimes cyclical depending on a number of factors among which changes in environmental conditions favor disease prevalence. Unknown disease may appear and cause loss. Therefore, regular surveillance for unknown diseases and knowledge on the scope and intensity of damage caused by any known disease is crucial. In this regard, major research focus in the past decade was given to disease survey, loss assessment, screening of maize genotypes against economically important diseases, chemical, cultural and botanical management and studies on ear, kernel and stalk rot diseases. The purpose of this review is, therefore, to provide a current status report on maize diseases and investigate the gaps and to provide recommendations for the future.

Major Research Achivements

Survey of maize diseases

Previous reports (Assefa and Tewabech, 1993, Tewabech *et al*., 2002) indicated that more than 47 diseases were recorded in maize. Currently, the number of diseases has increased and reached up to 65 in number. However, only 18 diseases which were not incorporated in the First or Second National Maize Workshop Proceedings are presented in this paper (Table 1). Field surveys conducted in the major maize growing regions indicated the variability of maize disease distribution, incidence and severity across geographic locations. Based on different reports, fungi, bacteria, virus and nematodes have been included. GLS, TLB, CR, MSV, *Phaeosophaeria* leaf spot (PLS) (*Phaeosophaeria maydis)* P.Henn, ear and kernel rots (*Fusarium* and *Gibberella* spp.) and storage diseases (*Fusarium*, *Penicillim* and *Aspergillus*) are the major and most important and which have received research focus for the past decades (Dagne *et al.,* 2001, Girma *et al.,* 2008). Although TLB and CLR were common in the past, their prevalence, distribution and incidence has been increased in recent years in all maize growing regions with a severity reaching 100% (Unpublished data). Some of the major maize diseases are discussed as follows.

Grey leaf spot (GLS)

GLS which has a very recent history of occurrence in Ethiopia has become the most important threat to maize production in the country (Dagne *et al*., 2001). Results of various surveys conducted in most maize growing regions indicated that the disease has distributed widely at an alarming rate and is considered to have significant impact on maize yield reduction in both local and improved varieties. A three year (2001, 2003 and 2004) survey showed that GLS is widely distributed and has severe outbreaks in East and West Wellega, Jimma, Illubabor, East Shewa, West Shewa, Sidama and north Omo zones of Ethiopia (Tables 2 and 3).

Turcicum leaf blight (TLB)

TLB is one of the widely distributed and economically very important diseases of maize production in the country. The infection appears during both off- and main-seasons, but it is more serious during the main-season in constantly wet and humid areas. High disease incidence and severity of TLB were recorded at Hawassa, Aleta Wondo, Enemor, Siraro, Sigmo Saxama, Bedele, Gimbi

Table 1. Importance, prevalence and distribution of maize diseases in major maize growing areas of Ethiopia.

Common name	Causal pathogen	†Prevalence	Importance	Distribution
Leaf spot	*Septoria maydis*	+	Minor	Gode, Wollaita, Assosa, Wellga
Leaf spot	*Leptosphaeria leaf spot*	+	Minor	Keffa, Holletta
Eyespot	*Kabatiella zeae*	+++	Moderate	Most surveyed areas
Brown spot	*Physoderma maydis*	+++	Major	Gofa, Dilla, Sha, Hw, BSF
Maize stunt virus	Mottel chlorotic stunt virus	+	Minor	Ambo
Bacterial strip	*Pseudomonas andropogonis*	+	Minor	Ambo, Alemaya, Pawe
Bacterial blight	*Pseudomonas avenae*	++	Moderate	EWW, Asossa, Ambo, Alemaya
Leaf spot	*Phyllosticazeae staut*	+	Minor	AN, Hawassa, EWW
Fals smut	*Ustilaginoidea urines*	++	Moderate	Hw, Sh, BSF
Ear rot	*Fusarium graminarium, Schw.*	+++	Major	Southern region
Ear rot	*Aspergillus nidulans*	+	Minor	Hawassa
Ear rot	*Diplodia maydis*	+++	Major	SR, Dd, Bk, Gambela.
Nematodes	*Heliocotylenchus coffere*	+	Minor	Horo Aleltu, Chora, Hawassa
Storage fungi	*F. subglutinans*	++	Moderate	Haraar, Shashemene
Storage fungi	*F. verticillioids*	+	Minor	Southern region
Storage fungi	*F. porliferatum*	+	Minor	Southern region/Hawassa
Storage fungi	*F. oxysporum*	+	Minor	Hawassa, Dehra, Melkasa
Storage fungi	*flatoxin/parsticicus*	+	Minor	Southern region/Hawassa

Source: Nardos *et al.* (2009), Tameru *et al.* (2009), Dagene *et al*. (2001), Tewabech *et al.* (2002), Girma *et al.* (2008). AN = Arsi Negele, BSF = Billito State Farm, Dd = Dedessa, EW = East Wellega, EWW = East and West Wellega, Hw = Hawassa, Sh = Shashemene, †intensity increases with '+' sign: + (<10%), ++ (11–30%), +++ (31–50%), ++++ (>51%).

Table 2. Incidence (Inc.) and severity (Sev.) of major maize leaf diseases in southern Ethiopia (2003 and 2004) (Mean of 5 locations per *woreda*).

		TLB		CR		GLS	
Zone	*Woredas*	Inc.%	Sev. (1–5)	Inc.%	Sev. (1–5)	Inc.%	Sev. (1–5)
Sidama	Hawassa Zuria	96	2.5	100	3.0	86	2.5
	Shebedino	84	3.0	100	3.0	70	2.7
	Boricha	70	2.3	72	2.5	54	2.1
	Dalle	80	2.5	56	2.5	59	2.7
	Aleta Wondo	100	3.0	58	2.6	100	3.6
	Agere Selam	67	2.5	45	2.1	80	3.0
North omo	Sodo Zuria	89	3.2	70	3.2	100	3.5
	Humbo	58	2.1	67	3.0	49	3.0
	OFA/Gesupa	62	2.5	58	2.6	50	2.3
	Damot weide	74	2.5	55	2.5	33	1.7
	Boloso Sore/Areka	86	3.5	90	3.5	100	3.5
Gedeo	Dilla/Wonago	88	2.5	70	3.0	68	2.5
	Yirga chefe	72	3.0	50	2.5	45	2.5
	Kochere	54	2.2	48	2.0	51	2.2
Gurage	Enemor	100	4.0	42	2.2	–	–
	Ener	82	3.0	38	2.0	–	–
	Zeway	52	2.3	100	3.2	25	2
East Shewa	Billito/Siraro	100	3.5	70	2.5	100	3.5
& West Arsi	Arsi Negelle	70	2.5	100	4.0	50	2.5
	Shashemene (shallo seed prodn. field)	80	3.0	91	3.0	72	2.5
	Ejaji	52	2.5	100	3.0	71	3.0
Special *woreda*	Halaba	50	2.0	52	2.0	50	2.5

Source: EIAR, Hawassa National Maize Project. – = not seen, TLB = *Turcicum* leaf blight, CR = common leaf rust, GLS = gray leaf spot.

and Bafano with incidence ranging from 95 to 100% for all *woredas* (localities) and severity ranging from 2.5 to 5.0 using a 1–5 scoring scale (Tables 2 and 3). In addition to Beletech, BH541, which was a high yielding cultivar, was banned from production due to the heavy infestation of TLB.

Common leaf rust (CLR)

CLR is also an important disease in Ethiopia. The disease is widely distributed throughout the major maize growing regions of the country. However, the importance varies from area to area. CLR is more severe in the southern mid-altitude areas of Ethiopia than in the western mid-altitude sub-humid areas. Although it was reported as sporadic in 2002 (Tewabech *et al*., 2002), it is becoming a key maize disease in southern parts of the country. The highest incidence was recorded at Hawassa, Shebedino, Arsi-Negelle and Ejaji *woreda* each with 100% incidence (Table 2). As a result, it is difficult to produce rust susceptible varieties like BHQP542 around Hawassa where CLR severity is high.

Phaeosophaeria leaf spot (PLS)

PLS is a maize leaf disease incited by *P. maydis.* In Ethiopia, the disease was first observed and registered as a minor disease in 1973 at Arsi-Negelle, Hawassa and around Wollega. Now, it is becoming an important disease around Jimma, Dedesa, Arjo, Bako and Hawassa areas. The highest incidence and severity was recorded from Sigmo, Saxama, Bedele and Gimbi *woredas* with incidence and severity ranging from 97 to 100% and 4.5 to 5.0 (1–5 scoring scale), respectively (Table 3).

Table 3. Incidence and severity of major maize diseases in western Ethiopia, in 2003 and 2004.

				PLS		GLS		TLB		CR	
Zone	***Woreda***	**Locality[†]**	**Variety**	**Inc%**	**Sev(1–5)**	**Inc%**	**Sev(1–5)**	**Inc%**	**Sev(1–5)**	**Inc%**	**Sev(1–5)**
Jimma	Omonada	Eldashne	BH660	65.8	1.9	81.3	2.4	63.3	2.1	53.8	1.5
		Coticha	BH660	38.3	2.1	88.8	3.1	64.6	2.3	58.3	1.5
	Sokoru	Algae	BH660	85.9	2.4	86.7	2.4	81.3	2.0	62.9	1.5
		Bidiru	BH660	82.9	2.5	86.7	2.1	59.2	1.6	67.5	1.6
	Sigmo	Ambo	Local	100.0	5.0	56.7	2.6	67.1	2.1	77.5	2.5
	Saxama	Jimmate	Local	96.7	4.5	85.8	2.6	81.7	2.6	69.2	1.6
Illubabora	Bedele	Cherise	BH660	99.2	4.0	87.9	1.8	57.5	1.9	72.5	1.8
		Qumbo	BH660	100.0	4.5	82.9	2.4	70.9	2.4	79.2	1.8
	Metu	Sore	Local	87.9	2.8	88.4	2.3	70.9	2.0	67.9	1.5
		Mendido	Local	82.6	1.9	84.6	1.6	81.3	1.8	80.4	1.5
	Darimu	Kulu	PHB30H83	82.9	1.9	60.8	1.5	95.0	2.4	77.1	1.5
		Haro	Local	72.1	1.9	75.9	1.6	71.7	1.9	60.9	1.6
		Gutiye	Local	83.4	2.5	86.3	2.5	77.5	2.1	63.0	1.6
West Wellega	Sayo	Amdo	BH660	88.7	2.0	91.7	2.0	98.3	2.8	65.8	1.5
		Gobaya Kamissa	BH660	86.3	1.6	91.7	2.1	90.8	2.1	51.3	1.5
	Iiraguliso	Kurfe	Local	81.3	1.6	60.4	1.6	85.4	2.3	41.7	1.5
		Kurfesa Birbir	PHB30H83	62.9	2.0	30.4	1.5	98.8	4.1	45.0	1.5
		Gemeda	BH140	86.7	2.4	65.0	1.6	97.5	2.9	56.3	1.5
	Gimbi	Nuri	BH660	100.0	5.0	73.3	1.8	94.6	2.9	61.3	1.6
		catolic	BH660	96.7	4.0	75.0	1.8	85.0	1.9	55.8	1.5
West Showa	Bako Tibe	laga Qala	BH660	44.2	1.1	90.7	1.9	81.4	1.8	27.1	1.1
		Olda oda	BH660	14.9	1.0	86.0	1.5	30.6	1.2	7.4	1.0
			Gutto	13.2	1.0	76.9	1.8	70.8	2.3	67.7	2.3
			Local	12.1	1.0	72.4	1.5	65.5	1.8	74.1	2.3
	Cheliya	Siba	BH660	27.3	1.0	94.2	2.6	48.8	1.5	19.0	1.0
		Qarsa	BH660	24.2	1.1	98.9	2.6	68.1	1.3	23.1	1.0
		Biche	BH660	35.2	1.0	83.8	1.6	87.7	1.3	16.2	1.0
East Wellega	Sibu Sire	Moto chekorsa	Pioneer hb	17.3	1.0	44.4	1.0	77.8	3.0	67.9	2.3
		Aroch	BH660	59.3	1.6	86.9	1.4	82.8	2.0	20.0	1.0
		Abulu	Local	53.0	1.5	76.9	1.4	81.2	2.1	19.7	1.0
	Gobu Sayo	Anno	BH660	43.4	1.3	83.8	2.1	35.8	1.4	38.7	1.1
		Baffano	BH540	14.9	1.0	74.3	1.0	100.	3.3	97.3	4.0
		Qejo	BH660	31.3	1.0	78.7	1.7	52.1	1.3	32.2	1.0

Source: Girma *et al*. (unpublished data). [†]Mean of four samples at each locality, PLS = Phaeosophaeria leaf spot, TLB = *turcicum* leaf blight, CR = common leaf rust, GLS = gray leaf spot.

Other diseases like downy mildew caused by *Sclerospora macrospora* were observed as an important disease in specific areas, around Anger, Gutin and Dedessa state farms. Head smut caused by *Sphacelotheca reliana* (Kuchn) Clint was sporadic in nature. Areas like upper Birr state Farm, Adama seed multiplication fields were the places where severe infection was observed. The disease has also been observed around Arsi Negele, Hawassa, Billito and Wondo Tica state farms, but not regularly. Leaf spot caused by *Hyalothyridium* sp. F. M. Lattereell has been observed at Kokate and Hawassa research sites during the 2004 cropping season.

Studies on seed borne fungal pathogens

Seed borne pathogens reduce the quality of seed for planting by lowering germination capacity, and lower its food and feed value by discoloration and the production of mycotoxins which are hazardous to human beings and animals. Various storage fungi including *Fusarium*, *Penicillim*, *Aspergillus,* and *Nigropora* spp. have been detected on samples collected from Bako, Hawassa, Areka, Billito, Shallo and Arsi Negele. All diseases were generally higher in samples collected from farmers' stores compared to research and seed multiplication stores. *Aspergillus* and *Fusarium* were more frequently isolated from damaged seeds followed by *Penicillim spp.* At Hawassa University, two sets of samples of 130 and 60, collected from six maize sites of Ethiopia were examined for *Fusarium* and *Aspergillus* in selective media (Nardos *et al*., 2009) and determination of mycotoxins was performed using reverse-phase High Performance Liquid Chromatography (HPLC) with fluorescence detection. *Fusarium* was the predominant genus. *F. verticlliods, F. proliferatum, F. sublutnans* and *F. oysprum* were isolated at different frequencies. Mycotoxin detection results showed the occurrence of Fuminosins (FB1and FB2), Aflatoxin (AFB1, AFB2, AFG1 and AFG2) and Ochratoxin A. The level of mycotoxin varied among samples. One hundred and eighty maize samples collected from four different zones in southern Ethiopia were also examined for different fungal moulds and mycotoxin contamination by using plating methods and direct competitive Enzyme Linked Immune Sorbent Assay (ELISA), respectively (Tameru *et al.*, 2009). Aflatoxin B1, Fumonisin B1 and Ochra toxin A were detected with mean concentrations of 22.7, 1679.3 and 147.3 µg kg^{-1}, respectively. Fumonisin B1 was found to be the dominant toxin both in pre-stored as well as stored maize sample. The toxin limits detected were significantly higher than the standard limit of many European countries.

Loss assessment study

Assessment of yield losses due to GLS was conducted at Bako for three years (1999–2001) (Dagne *et al.,* 2004). The response of three commercial varieties with different levels of resistance to GLS, namely, BH660, BH140 and PHB3253 and three treatments (inoculated, fungicide sprayed and unsprayed control) were used for the study. The results indicated that varietal effects were significant for 1,000 kernel weight and grain yield, while treatment effects were significant for ear diameter and grain yield. Mean kernel and grain yield losses ranged from 1.7 to 10.0% and 7.8 to 29.1%, respectively, on different varieties. The result indicated that GLS could be severe in some favorable seasons causing significant yield losses even on resistant varieties (Dagne *et al*., 2004).

Table 4. Effect of grey leaf spot on mean grain yield and yield components of three maize varieties at Bako.

Variety	Treatment	Ear length (cm)	Ear diameter (cm)	Thousand-kernel weight		Grain yield	
				g	% loss	t ha^{-1}	% loss
BH660	Inoculated	19.5	4.4	325.9	1.7	9.5	7.8
	Control	19.9	4.6	350.1	–	9.4	8.5
	Sprayed	19.5	4.4	331.6		10.3	
BH140	Inoculated	17.6	4.5	285.1	7.9	7.5	16.6
	Control	18.3	4.6	313.6	–	8.2	9.1
	Sprayed	18.4	4.7	309.5		9.0	
PHB3253	Inoculated	17.3	4.6	283.8	10.0	5.6	29.1
	Control	18.2	4.8	314.7	–	7.1	10.2
	Sprayed	17.4	4.7	315.4		8.0	
	Mean	18.5	4.6	314.4		8.3	
	CV%	5.2	3.1	8.2		16.9	

Source: Dagne *et al*. (2004). Means were calculated over all data from the 1999, 2000 and 2001 cropping seasons.
CV = coefficient of variance.

A study conducted by Meseret and Temam (2008) using varieties, BH660, BH540 and PHB3253 has also shown grain yield loss due to gray leaf spot disease under different tillage practices. As a result, grain yield loss and 1,000 kernel weight (KW) loss were decreased as the level of tillage increased from no till to conventional tillage. The highest grain yield loss (1.6, 24, and 27%) and 1,000 KW loss (1.1, 4.7 and 4.3%) were recorded under no tillage in BH660, BH540 and PHB3253 varieties, respectively (Table 5). Higher grain yield reduction was observed in the maize hybrid PHB3253 ranging from 21 to 27%, followed by BH540 ranging from 14 to 18%. In the case of BH660 maize hybrid, there was not much difference in yield when inoculated or sprayed (Table 5). However, the yield losses ranged from 0.0 to 14.9 and this indicates that the hybrid may have some level of tolerance to the pathogen.

Control Measures

Varietal screening

Sources of resistance have been reported in varieties and elite materials against diseases. At Bako a maize TLB nursery was started in collaboration with East Africa Regional Maize Nursery in 1998. Screening was started with 85 materials received from CIMMYT, Zimbabwe. Fifteen well performing lines were evaluated for final proof of resistance to major diseases of maize in 2002. The results indicated that entry numbers 6, 13, 7, 3, and 4 were found to be relatively resistant to GLS, while, entries number 6, 13, 14 and 5 were found to be relatively resistance to TLB (Table 6). In line with this, a TLB and GLS disease advanced nursery was started in collaboration with the East Africa Regional Maize Nursery in 2000. Screening was started with 130 materials received from CIMMYT, Zimbabwe. Twenty well performing lines were evaluated for final proof of resistance to major diseases of maize in 2002. Based on across year evaluations of the materials for resistance to GLS and TLB, entry numbers 17, 5, 16, 8, 18 and 11 were found to be resistant to GLS, while entry numbers 10, 4, 11, 5, 8, 16, 19, 9 and 20 were identified as resistant to TLB (Table 7). Another study was also carried out to evaluate local materials for resistance to GLS at Bako, Jimma and Awassa. The results indicated that materials such as 139-4-1, 143-5-b and 143-7-2 showed relative resistance and 136-a, F7189 and 143-5-I were moderately resistance (Table 8). Very recently at Bako, evaluation of normal and quality protein maize (QPM) materials was initiated with 123 materials in 2004. Finally, 48 materials, which were found to be promising, were tested under artificial inoculation in 2006. The

Table 5. Varieties and corresponding losses due to gray leaf spot under different tillage at Bako, 2006 cropping season.

Tillage practice	Variety	Fungicide treatment	Grain yield (kg ha^{-1})	Loss (kg ha^{-1})	Loss (%)	TKW (g)	Loss (g)	Loss (%)
No tillage	BH660	M0	8,553	137	1.6	316.2	3.5	1.1
		M1	8,690			319.7		
One time tillage	BH660	M0	8,741	31	0.3	320.5	3.0	0.9
		M1	8,772			323.4		
Two times tillage	BH660	M0	8,968	144	2.0	325.0	3.0	0.9
		M1	9,112			328.0		
Three times tillage	BH660	M0	9,174	154	1.0	333.5	3.0	0.9
		M1	9,328			336.5		
No tillage	BH540	M0	6,274	2,025	24.0	252.7	12.5	4.7
		M1	6,589			265.2		
One time tillage	BH540	M0	6,613	1,701	20.0	264.0	4.4	1.6
		M1	8,314			268.4		
Two times tillage	BH540	M0	8,201	919	11.0	294.2	4.1	1.4
		M1	9,120			298.3		
Three times tillage	BH540	M0	8,175	986	10.0	299.8	3.9	1.3
		M1	9,161			303.7		
No tillage	PHB3255	M0	6,274	2,314	27.0	264.6	11.8	4.3
		M1	8,588			276.4		
One time tillage	PHB3255	M0	6,552	1,929	22.0	263.1	11.8	4.3
		M1	8,481			274.9		
Two times tillage	PHB3255	M0	7,527	1,359	15.0	252.0	10.7	4.0
		M1	8,886			262.7		
Three times tillage	PHB3255	M0	7,804	1,122	13.0	264.2	2.2	0.8
		M1	8,926			263.0		
LSD (5%)			1,685			67.18		

M1 = sprayed with fungicide, M0 = unsprayed with fungicide, TKW = thousand kernel weight, LSD = least significant difference.

results indicated that 17 entries (33, 35, 25, 29, 21, 16, 20, 2, 47, 23, 15, 13, 1, 38, 14, 30 and 22) were found to be resistant to GLS and 11 entries (25, 19, 18, 34, 14, 22, 21, 32, 2, 1 and 33) were found to be resistant to TLB (Table 8) (Girma, unpublished data).

A total of 118 genotypes obtained from Bako national maize research project were evaluated under Hawassa conditions against CLR, TLC and GLS diseases. Promising materials from these collections that consist of 48 maize genotypes were reevaluated at Hawassa in the 2005 cropping season, of which seven genotypes namely, 142-1-e, 144-7-b, CML339, SZSYNA 99-F2-2-2-1, SZSYNA 99-F2-2-7-3, SZSYNA 99-F2-7-2-1 and CML179 were found be tolerant to CLR, TLC and GLS diseases.

Dagne *et al.* (2003, 2008) evaluated the resistance of 28 F_1 crosses and eight inbred parents against GLS disease for two years under artificial inoculation at

Table 6. Evaluation of CIMMYT lines for resistance to *turcicum* leaf blight (TLB) and gray leaf spot (GLS).

No.	Entries	Average severity TLB	Average severity GLS
1	[INTB-F2-111-3/INTB-277-1-2]-X-2-1-4-B-B	1.8ab	2.1bcde
2	Sc (PHAM)-3/[[CML-205/Sc//CML-202]-X]-4-B-B	1.7ab	1.7defg
3	DRB-F2-60-1-2-B-1-B-B-B	1.7ab	1.4fg
4	LATA-26-1-1-1-1-6-B-B	2.0a	1.7efg
5	[[NAW5867/P30-SR]-40-1/[NAW5867/P30-SR]-25-1-2-2-B-1	1.7bc	2.3abc
6	DRA-F2-141-2-1-1-B-4-B-B	1.4c	1.3g
7	DAB-F2-60-1-2-B-1-1-B-B	1.8ab	1.4fg
8	[DRA-F2-5-2/ DRA-F2-70-3]-X-7-2-4-B-B	1.8ab	1.9bcde
9	[SNSYN-F2 (N3) TUX-A-90]-102-1-2-2-2-BSR-B-2-B-B	1.8ab	2.1bcde
10	DRA-F2-141-3-2-1-1-B-B	1.8ab	2.6a
11	[INTB-277-1-2/ INTB-197-2-1]-x-9-2-1-B-B	1.8ab	1.9cdef
12	ZM-605-C2-F2-428-3-B-B-B-B-B	1.8ab	1.8defg
13	DRA-F2-141-2-1-1-10-B-B	1.6bc	1.4fg
14	Sc (PHAM)-3/[[CML-205/Sc//Sc]-X]-1-1-B-B	1.6bc	2.4ab
15	LATA-26-1-1-2-1-1-B-B	1.7ab	2.2abcd
	CV (%)	9.0	13.1

Source: Bako National Maize Research Project (2002). Means followed by the same letter(s) in a column are not significantly different at P<0.05. CV = coefficient of variance.

Table 7. Evaluation of CIMMYT lines for resistance to gray leaf spot (GLS) and *turcicum* leaf blight (TLB).

No.	Entries	Average severity GLS	Average severity TLB
1	[LZ966205/LZ966017]-B-2-1-6-B-B	2.0cde	2.0abc
2	[LZ955459/LZ955357]-B-1-4-6-B-B	2.1bcd	1.8bcde
3	[DRB-F2-180-2/DRB-3-4-1]X-6-1-3-B-B-B	1.7efg	2.1a
4	[LZ955459/LZ955357]-B-1-5-1-B-B	2.0cde	1.5f
5	[LZ966077/LZ966205]-B-3-2-2-B-B	1.2h	1.5def
6	[CML-216/CML204//CML-202] X-29-2-B-B-B	2.2bcd	1.8bcde
7	[INTA-241-2-1-/INTA2-1-3] X 11-3-1-B-B	1.8def	1.8bcde
8	[LZ955459/LZ955357] 1-5-2-B-B	1.4gh	1.6def
9	[LZ966205/MSR123X1137TN-9-2-4X3]-B-1-3-1-B-B	1.8def	1.6def
10	[DRB-F2-23-1/DRB-39-2-2] X-6-1-2-B-B	2.8a	1.5f
11	[LZ966077/LZ966205]-B-3-2-5-B-B	1.4gh	1.5ef
12	[INTB-91-1-2/INTB-F2-111-3] X-8-2-1-B-B	2.1bcd	1.8bcd
13	[LATA-76-1-1/LATA-F2-196-2] X 1-1-2-B-B	2.3bc	1.7cdef
14	[CML-205/K64R//CML-202] X-8-1-B-B-B	2.4ab	1.7cdef
15	[DRA-F2-5-2/DRA-F2-20-3] X-7-1-2-B-B	2.4ab	2.0ab
16	[LZ956348/LZ956003]-B-1-1-2-B-B	1.2h	1.6def
17	[CML-205/CML-208/CML-202] X-21-2-B-B-B	1.1h	1.7bcdef
18	[INTA-2-1-3/INTA-43-3-2]-3-6-2-B-B	1.4gh	1.8bcd
19	[LZ955459/LZ955357]-B-1-4-1-B-B	1.7efg	1.6def
20	[LZ955459/LZ955357]-B1-5-5-B-B	1.6fg	1.6def
	CV (%)	12.2	9.9

Source: Bako National Maize Research Project (2003). Means followed by the same letter(s) in a column are not significantly different at P<0.05. CV = coefficient of variance

Table 8. Evaluation of normal and quality protein maize (QPM) germplasm for resistance to gray leaf spot (GLS) and *turcicum* leaf blight (TLB).

No.	Entries	Average severity record for GLS	Average severity record for TLB
1	142-1-e	1.3ijkl	1.3jk
2	144-7-b	1.2jkl	1.3jkl
3	124-b (109)	2.7bcde	2.1bcdefgh
4	CML197	3.4ab	3.2a
5	101-E	3.4ab	2.2bcdefg
6	FH-625-251-1	2.2cdefghi	2.0bcdefghij
7	Z-76-12	2.9bc	1.9bcdefghijk
8	Z-76-25	1.9cdefghijkl	1.7efghijk
9	CML339	2.7bcde	2.1bcdefgh
10	CML387	2.8bcde	1.9cdefghijk
11	F7189	1.9defghijkl	1.6efghijk
12	Pool 9A-134-2-3-2-3	2.3cdefgh	1.7efghijk
13	SZSYNA 99-F_2-2-2-1	1.3ijkl	1.9bcdefghijk
14	SZSYNA 99-F_2-2-2-2	1.3ijkl	1.4ghijk
15	SZSYNA 99-F_2-2-2-3	1.3ijkl	1.7efghijk
16	SZSYNA 99-F_2-2-3-2	1.2jkl	1.6fghijk
17	SZSYNA 99-F_2-2-7-1	1.9defghijkl	1.8cdefghijk
18	SZSYNA 99-F_2-2-7-2	1.6hijkl	1.5fghijk
19	SZSYNA 99-F_2-2-7-3	1.6hijkl	1.5fghijk
20	SZSYNA 99-F_2-3-6-2	1.2jkl	1.7efghijk
21	SZSYNA 99-F_2-3-6-3	1.2jkl	1.4ghijk
22	SZSYNA 99-F_2-3-6-4	1.5hijkl	1.4ghijk
23	SZSYNA 99-F_2-3-7-2	1.2jkl	2.2bcdefg
24	SZSYNA 99-F_2-3-7-3	2.8bcde	2.1bcdefghi
25	SZSYNA 99-F_2-7-2-1	1.1kl	1.5fghijk
26	SZSYNA 99-F_2- 33-4-1	1.7ghijkl	2.0bcdefghij
27	SZSYNA 99-F_2- 33-4-2	3.5ab	2.0bcdefghij
28	SZSYNA 99-F_2-80-3-2	3.7a	1.9cdefghijk
29	SZSYNA 99-F_2-80-3-4	1.1kl	2.2bcdef
30	SZSYNA 99-F_2-80-3-6	1.4ijkl	1.8defghijk
31	SZSYNA 99-F_2-133-2-1	1.7ghijkl	1.6efghijk
32	SZSYNA 99-F_2-133-2-3	2.2cdefghij	1.4hijk
33	SZSYNA 99-F_2-81-4-3	1.0l	1.2k
34	SZSYNA 99-F_2-98-4-3	1.8fghijkl	1.4ghijk
35	SZSYNA 99-F_2-124-8-1	1.1kl	2.4bcd
36	CML141	3.9a	2.2bcdefg
37	CML142	2.5cdefg	2.6b
38	CML143	1.3ijkl	1.9cdefghijk
39	CML144	2.0cdefghijkl	1.8defghijk
40	CML160	2.1cdefghijk	1.9cdefghijk
41	CML173	2.8bcd	2.3bcde
42	CML174	1.8efghijkl	2.3a
43	CML179	3.6ab	1.7efghijk
44	CML182	2.8bcde	1.7efghijk
45	CML183	2.7bcdef	1.7efghijk
46	CML191	2.8bcde	1.9cdefghijk
47	CML194	1.2jkl	2.0bcdefghij
48	SC22	2.5cdefg	2.5bc
	CV(%)	15.5	11.7

Source: Bako National Maize Research Project (2006). Means followed by the same letter(s) in a column are not significantly different at P<0.05. CV = coefficient of variance.

Bako. Significant differences were observed among the entries for GLS disease resistance. Parental line CML387 showed a highly resistant reaction to GLS disease followed by 143-5-i. Most crosses involving one of these inbred lines as their parents showed more resistant reaction to the disease than other crosses. While inbred lines A7016, CML197 and CML202 tended to increase susceptibility of the disease (Dagne *et al*, 2009). Another study was also carried out to evaluate local materials for resistance to GLS at Bako, Jimma and Hawassa. The results indicated that materials such as 139-4-1, 143-5-b and 143-7-b showed relative resistance and 136-a, F7189 and 143-5-I are moderately resistant (Table 9).

Cultural Practice

Cultural practices such as adjusting planting date, managing plant density, crop rotation and fertilizer application (Tewabech *et al.*, 2002; Girma *et al.*, 2008) and tillage effect (Meseret and Temam, 2008) have comprehensively been reviewed in reducing incidence of certain maize diseases. The onset of certain diseases in maize with respect to cultural practice varied within locations and seasons.

Effect of planting date on disease intensity

GLS was observed on both late- and early-planted maize on a field trial conducted at Billito farm indicating the perpetuated effect of the disease as far as maize plants are available. However, the disease severity was almost as high as 100% on late planted (5–18 May) maize and ultimately caused kernel shriveling (Field visit report, 2003). The same result was also reported by Fekede and Kedir (2004) where disease severity and Area Under Disease Progress Curve (AUDPC) of GLS was significantly ($P < 0.05$) lower at early planting (mid May) while late planting maize (early June) had higher disease severity and AUDPC. Significantly higher yield (5%, 6.7 t ha^{-1}) was obtained from early planted maize as compared to the late planting (4.5 t ha^{-1}). The justification behind this was that GLS has its highest effect when it appears earlier in the crop growth stage than later.

Table 9. Evaluation of local lines for resistance to gray leaf spot (GLS) disease.

No.	Entries	Average GLS severity records at three locations: Bako	Jimma	Hawassa
1	136-d	1.4a	1.5abc	1.3b
2	143-5-i	1.4a	1.3cde	1.4ab
3	Gutto-original	1.4a	1.7a	1.3ab
4	143-7-b	1.2b	1.2cde	1.2c
5	139-4-1	1.2b	1.3cde	1.1c
6	143-5-b	1.2b	1.1e	1.1c
7	136-a	1.2b	1.3cde	1.3b
8	132-7-b	1.4a	1.5abc	1.4a
9	F7189	1.3ab	1.2de	1.4a
10	CML393	1.3a	1.6ab	1.4a
11	SC22	1.4a	1.4bcd	1.4a
LSD		0.1	0.2	0.1
CV (%)		5.7	10.6	4.6

Source: Bako National Maize Research Project (2001). LSD = least significant difference, CV = coefficient of variance.

Another planting date assessment was conducted at Jimma on grain yield and severity of three major diseases of maize using four commercial maize varieties (BH660, UCB, Gutto and Kuleni) and five planting dates (April 20, May 5, May 20, June 5 and June 20) for three years (2000–2002). The result indicated that the East African varieties, UCB and BH660, showed significantly lower disease severity compared to Gutto which is of CIMMYT origin (Table 10). Planting date has significantly ($P < 0.01$) influenced the severity of CLR producing significantly lower grain yield. Based on grain yield and disease evaluation, May 5 to 20 was recommended as the optimum planting date for maize in south-western Ethiopia (Leta, 2005).

Effect of tillage, fungicide and variety

Severe damage of GLS epidemics (84.6%) were observed in fungicide unsprayed plots of PHB3253 grown under no-tillage practice and one time tillage (80%) practice, while the lowest (34.7%) GLS epidemics were observed on fungicide sprayed plots of BH660 under conventional tillage (Meseret and Temam, 2008). When maize was planted in no-tillage treatments where the field was infested with maize residues harboring *Cercospora zeae-maydis* that remained on the soil surface, the progress of the epidemics were faster. It reached more damaging levels than in maize planted in a conventionally tilled field. This was because infested residue either was absent or greatly reduced due to inversion of the residue to the soil.

Evaluation of botanicals

Ten different essential oils namely, orange peel (*Citrus sinensis*), rosemary (*Rosmarinos officinalis*), black cumin (*Nigella sativum*), white cumin (*Cuminum cyminum*), palmarosa (*Cymbogogon* spp.), tosign (*Thymus vulgaris*), black pepper (*Piper nigrum*), Lavender (*Lavendula anguistifolia*), Citrodora (*Cympobogon* spp.) and Mexican tea (*Chenopodium ambrosioides*) were tested under laboratory conditions for their antifungal activity against isolates of *A. flavus* and *F.verticelliods*. All the tested oils inhibited myclila growth to a different extent. Compared to the others Palmarosa and white cumin induced complete inhibition of fungal growth of both isolates at the lowest concentration (0.25% V/V). As the concentration increases (1.25%V/V) some of the oils also exhibited similar effects. The experiment indicates that large-scale screening of the oils on both fungal growth and mycotoxin production is required (Nardos *et al.*, 2009).

The potential effect of 13 botanicals at the rate of 60 kg ha^{-1} with application frequency of 6 sprays in a crop season in comparison to a standard chemical (Mancozeb 80% WP) and untreated control were evaluated against CLR and TLB at three locations (Hawassa, Areka and Arsi-Negelle). Eucalyptus (*Eucalyptus globules*) and papaya crude leaf (*Carica papaya*) provided promising results in reducing diseases and increasing yield compared to the other botanicals and the untreated control plot. The greatest yield 6,584 kg ha^{-1} was obtained for standard control fungicide Mancozeb 80% WP sprayed plots followed by Eucalyptus leaf (5,851 kg ha^{-1}) and papaya leaf 5,630 kg ha^{-1}. The non-spray control plot gave 4,120 kg ha^{-1}. Application of both *E. globules* and *C. papaya* is very promising, except the high rate required, and can serve as a component of integrated management of maize leaf diseases (Table 11).

Table 10. Mean severity of diseases evaluated on maize varieties planted at different dates for three years at Jimma (2000–2002).

		Planting date					
Diseases	Varieties	April 20	May 5	May 20	June 5	June 20	Mean
Common rust	BH660	1.5(1.2)	1.7(1.2)	1.3(1.1)	1.2(1.0)	1.0(1.0)	1.3(1.1)[b]
	UCB	1.4(1.2)	1.4(1.1)	1.2(1.1)	1.0(1.0)	1.0(0.9)	1.2(1.1)[b]
	Gutto	2.1(1.3)	2.3(1.3)	2.4(1.4)	2.2(1.3)	2.2(1.3)	2.3(1.3)[a]
	Kulani	1.9(1.2)	1.7(1.1)	1.5(1.2)	1.2(1.0)	1.0(1.0)	1.4(1.1)[b]
	Mean	1.7(1.2)[a]	1.7(1.2)[a]	1.6(1.2)[a]	1.4(1.1)[b]	1.3(1.1)[b]	
turcicum leaf blight	BH660	1.9(1.3)	1.9(1.28)	2.1(1.32)	2.1(1.32)	2.2(1.31)	2.1(1.3)[b]
	UCB	1.9(1.3)	1.9(1.28)	1.8(1.26)	1.9(1.26)	2.1(1.30)	2.0(1.3)[b]
	Gutto	2.4(1.4)	2.5(1.39)	2.8(1.43)	2.7(1.41)	2.7(1.40)	2.6(1.9)[a]
	Kulani	2.3(1.3)	2.2(1.3)	1.8(1.3)	1.6(1.3)	1.4(1.3)	1.9(1.3)[b]
	Mean	2.2(1.3)[a]	2.2(1.3)[a]	2.2(1.3)[a]	2.1(1.3)[a]	2.1(1.3)[a]	
Gray leaf spot	BH660	2.3(1.3)	2.3(1.4)	2.3(1.4)	2.3(1.4)	2.6(1.4)	2.4(1.4)[ab]
	UCB	2.2(1.3)	2.1(1.3)	2.3(1.3)	2.3(1.4)	2.4(1.4)	2.3(1.3)[b]
	Gutto	2.7(1.4)	2.6(1.4)	2.6(1.4)	2.2(1.3)	2.3(1.3)	2.5(1.4)[a]
	Kulani	2.7(1.4)	2.4(1.4)	2.3(1.4)	2.5(1.4)	2.6(1.4)	2.5(1.4)[a]
	Mean	2.5(1.4)[b]	2.4(1.4)[b]	2.4(1.4)[b]	2.3(1.4)[b]	2.6 (1.4)[b]	

Source: Leta (2005). Means followed by the same letters are not significantly different from each other at P < 0.05. Data in parentheses have been transformed.

Table 11. Influence of botanicals in controlling maize disease combined over three locations (2002–2003).

		Disease incidence %			Disease severity (1–5 scale)			Yield
No.	Treatment	TLB	CR	GLS	TLB	CR	GLS	(t ha^{-1})
1	Castor seed (*Ricinus communes*)	30.9 b–d	29.1 bc	8.4 a	2.5 bc	2.4 b–d	1.4 a	4.41 c
2	Datura seed (*Datura stromonium*)	35.8 a–c	40.3 b	8.2 a	2.8 ab	2.7 b	1.4 a	4.52 c
3	Datura leaf (*Datura stromonium*)	39.7 ab	44.3 b	8.7 a	2.9 ab	2.9 b	1.5 a	4.39 c
4	Neem seed (*Azadrechata indica*)	28.1 b-d	33.9 c	10.2 a	2.5 bc	2.5 b–d	1.6 a	5.00 bc
5	Eucalyptus leaf (*Eucalyptus globules*)	18.7 cd	20.6 c	9.6 a	2.0 cd	2.1cd	1.5 a	5.85 ab
6	Croton leaf (*Croton macrostachys*)	41.9 ab	45.0 b	7.7 a	2.8 ab	2.9 b	1.4 a	4.40 c
7	Tobacco leaf (*Nicotina tabacum*)	41.9 ab	44.8 b	8.8 a	2.9 ab	2.9 b	1.6 a	4.39 c
8	Papaya leaf (*Carica papaya*)	19.6 cd	21.9 c	9.5 a	1.9 d	2.0 d	1.6 a	5.63 ab
9	Lemon fruit (*Citrus lemion*)	39.0ab	42.6 b	10.0 a	2.8 ab	2.9 b	1.5 a	4.35 c
10	Grawa leaf (*Vernonia amigdalina*)	42.0ab	40.1 b	8.6 a	2.8 ab	2.7bc	1.5 a	4.38 c
11	Emboai fruit (*Solanum*)	40.4 ab	44.9 b	9.8 a	2.9 ab	3.0 b	1.6 a	4.36 c
12	Garlic bulb (*Allium sativam*)	44.1 ab	41.4 b	8.9 a	2.9 ab	2.7 bc	1.6 a	4.53 c
13	Feto seed (*Lepidium sativam*)	42.4 ab	44.4 b	9.5 a	2.8 ab	2.9 b	1.6 a	4.57 c
14	Fungicide (Mancozeb 80%WP) control	16.0 d	18.8 c	8.7 a	1.9 d	1.91d	1.4 a	6.58 a
15	Untreated (control)	54.0 a	60.4 a	11.6 a	3.4 a	3.8 a	1.7 a	4.12 c
	LSD (0.05)	15.9	14.2	NS	0.5	0.5	NS	0.91
	CV%	27.6	23.1	32.5	12.9	12.3	15.	11.8

Means followed by the same letter(s) in a column are not significantly different at P<0.05.. TLB = *turcicum* leaf blight, CR = common rust, GLS = gray leaf spot.

Conclusion and Recommendations

Although substantial information on the occurrence of maize disease is available in major maize producing regions, variation in diseases' intensity is observed. Hence the relative importance of maize diseases needs to be prioritized based on the environmental factors and production system. Pre- and post-harvest yield losses due to storage diseases are not well quantified. The findings reviewed on cultural practices are encouraging and farmers need to be advised to adopt the proven practices, in the absence of resistant varieties. However, the combined effect of all cultural practices is not yet known. Additional research is needed to determine to what extent the practice provides a yield advantage and compare the competitive survival of certain diseases between systems and in relation to wheather conditions.

Future Directions

- More extensive studies for assessment of varieties for specific regions and identification of resistant varieties against major diseases need to be emphasized.
- Development of appropriate cultural, botanical, chemical and biological disease management techniques need to be emphasized.
- Establishment of green houses and upgrading of laboratories for photology research should be emphasized.

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Participatory on-Farm Maize Technology Evaluation and Promotion in Ethiopia

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Introduction

Maize is among the major crops sold for cash and has been a chief contributor to meeting household food security (farmers' primary objective) over the years (Asfaw *et al.,* 1997). Millions of smallholder farmers in the major maize producing regions of Ethiopia depend on maize for their daily food (CIMMYT and EARO, 1999).

In almost all major maize growing areas of the country, maize is one of the staple foods. However, its production is constrained by various biotic and abiotic as well as socioeconomic factors such as diseases and pests, poor soil fertility, erratic rainfall, scarcity of land in the highland areas, seasonal labor shortage, insufficient supply of inputs and credit. In parallel with these constraints, low technological adoption, poor access to market by small holder farmers and limited technological options for the very diverse agro-ecologies and farmers' circumstance have also been bottlenecks for increasing maize production and productivity.

In response to the different technological and socioeconomic production constraints, the National Maize Research Program has been making a concerted effort in developing suitable technological options. Accordingly, several improved maize technologies addressing different production constraints of the various target production areas have developed during the last few decades. These varieties have demonstrated great productivity potential as well as added nutritional value in resolving protein deficiencies in areas where maize is a major stable.

The technologies developed provide better options for the farming communities in maize production thereby contributing to the household food security and improved nutritional status in Ethiopia. There have been efforts to introduce improved maize technologies during and prior to the 1990s which has contributed to the increase in the national maize productivity (Takele, 2002). Moreover, with the emergence of new production and utilization challenges and development of new technological options during the last decade, continuous efforts to create awareness and interest in the new varieties remains central to boosting productivity and livelihoods. Accordingly, a number of on-farm demonstration and evaluation activities were carried out to enhance technology adoption by the maize farmers in targeted locations. These research activities were carried out with the objective of introducing new cropping technologies, gathering farmers' assessment of the technologies, identifying and popularizing their preferences. Additionally, the research activities identified the challenges and opportunities that hindered the adoption and dissemination of improved maize technologies developed for different target production areas. Although different maize technology popularization activities were conducted in different parts of the country, this paper focuses on on-farm demonstrations and promotion activities in the central rift valley, western, south-western and the central highland maize production zones.

Technology Demonstration and Promotion Approaches

Different approaches (farmer groups and individuals) were adopted and employed in the process of demonstration, evaluation and promotion of the improved maize technologies in the low moisture stress areas, mid-altitude and highland maize growing areas of the country during the last ten years (Table 1). In all cases, the farmer groups as well as the individual host farmers were identified and briefed well ahead of time in preparation for the on-farm demonstration activities. The varieties promoted consisted of quality protein maize (QPM) and non-QPM hybrids and open-pollinated varieties (OPVs) with the recommended management practices.

The on-farm demonstration and evaluation activities in the central rift valley were conducted using Farmer Research Groups (FRGs) by Melkasa Agricultural Research Center (MARC). Five maize FRGs were established in three districts of East Shewa zone. In Adama (Adulala and Awash Melkasa), Boset (Dongore Tiyo and Dongore Furda) and Adami Tulu (Anano Shisho) each with 10 to 18 member farmers. Prior to formation of the farmer groups, detailed discussions were held with the local farming community and agricultural development agents (DAs) to identify major maize production constraints contributing to lower grain yield on farmers' fields as compared to the yield potentials observed at the research stations.

Table 1. Locations, year, varieties used and cultural practices applied.

Target locations	Year	Varieties	Cultural practices and number of participant farmers
Central rift valley (East Shewa Zone)	2005–2010	Melkasa2 Melkasa3 Melkasa4 Melkasa6Q A511 Local varieties	Plot size: 0.125–0.25 ha; Seed rate: 25–30 kg ha^{-1}; Spacing: 25cm between plants and 45–60 cm between rows (the spacing opened by local plough); Planting date: from second week of May to first week of June at all locations. Fertilizer: DAP: 100 kg ha^{-1} at planting and Urea: 50 kg ha^{-1} during first cultivation (*shilshalo*) about 40 days after planting. 1–2 times weeding while hoeing was done twice only at one site (Anano shisho). Participant host/demonstration farmers: 111
Western Ethiopia (West Welega and Bako area)	2003–2005	BHQP542 Gibe1 BH670 Local variety	Plot size 30 m × 30 m; Spacing: 75 cm × 30 cm; Seed rate: 25 kg ha^{-1}; 2–3 times ploughing; Fertilizer: 200 kg ha^{-1} urea and 100 kg ha^{-1} DAP for Bako area, 150 kg ha^{-1} urea and 150 kg ha^{-1} DAP for west Wollega and twice hand weeding (first weeding 25–30 days and second weeding 55–60 days after planting) were used. Participant farmers: 400
South western Ethiopia (Jimma)	2007	Morka, Kuleni, Gibe1, UCB C_0	On-station and on-farm variety verification across different agro-ecologies
Central Highland (Ambo, Holetta, Guraghe)	2005–2009	Arganne, Hora, Wenchi, Jibat	Mainly promotional and popularization/scaling up activities

Three to five farmers from each FRG were selected to host the demonstration trials and apply the necessary crop management practices, as agreed, while the other member farmers were regularly brought to the host/trial farmers' site for joint monitoring and evaluation. Group field visits were conducted four times at different growth stages of the crop growing period. Observable parameters were identified and recorded in discussion with farmers at different stages of the crop growth; i.e., emergence, first cultivation at vegetative stage (*shilshalo*), flowering and maturity. Additional parameters considered at maturity included plant height, ear height, cob size, number of cobs per plant, spacing between plants, spacing between rows and grain yield. In the farmers' practice, spacing between rows and between plants was recorded just before harvest during the 2007 cropping season. To measure inter-row spacing, the total number of rows in all treatments were counted, their cross-sectional width measured and then divided by the total number of rows. To determine the spacing between plants, a 5 m length row was taken randomly 4 times for each treatment and the total number of plants counted and their average was calculated. The data collected were analyzed using simple descriptive statistics and tabulation.

Comprehensive training on maize production practices was organized for the farmer groups (participant farmers), DAs and *woredas'* extension experts. In addition, field days were organized every year to create awareness about the new maize technologies and stimulate interest for adoption by surrounding farmers. Accordingly, the improved maize varieties were observed and assessed along with the local variety by the host and non-host farmers. Moreover, the best performing maize varieties with their recommended management practices were demonstrated to a large number of farmers in different maize production zones. For this purpose, scaling up as well as community-based seed production activities were carried out to ensure maximum reach in the target areas.

Achievements of Technology Demonstration and Promotion Activities

The results of the activities are summarized for the different maize production areas of the country. The areas included are the central rift valley, central highland, western and south-western areas.

Central rift valley

The central rift valley (CRV) lies in the central lowland area of the country. The rainfall is erratic and moisture remains one of the limiting factors to production. In addition, from the discussion that took place with farmer groups, maize production constraints were described and areas for joint research and development interventions were identified. Accordingly, lack of a suitable variety for the dryland, shortage of inputs, inappropriate crop management practices (no hoeing, low rate of fertilizer application and untimely cultivation) were found as the most important constraints. In order to tackle these constraints, in 2005, demonstration and evaluation of medium maturing drought tolerant maize varieties was launched, comparing them with the farmers' varieties and practices (high seed rate with no chemical fertilizer). The drought tolerant maize varieties developed by the maize research program for moisture-stressed areas were demonstrated and promotion activities were carried out with the aim of creating awareness and improving farmers' access to the improved maize technologies in the area.

On-farm variety evaluations and demonstration (2005–2010)

During 2005, the medium maturing variety Melkasa2 was demonstrated on farmers' fields against A511 and local varieties. It performed better than both checks by 18 and 140% (Table 2). Melkasa2, in addition, was found to be earlier in maturity than the checks; hence, it was preferred by the farmers for this character also.

In 2006, another medium maturing maize variety, Melkasa3, was also demonstrated on farmers' fields along with the local check and produced on average 21% better grain yield. The grain yield advantage varied from location to location within the range of 17–51% (Table 3). The farmers' opinion and preferences were also recorded at maturity. All the participating farmers preferred Melkasa3 better than the check because of its early maturity, tolerance to lodging, well-filled grain and larger cob size.

In 2007, the two medium maturing and drought tolerant varieties (Melkasa2 and Melkasa3), were demonstrated to farmers compared with A511 in the farmers' field. Fertilizer application was the major difference between farmer management and improved management practice, in that, only 4 out of the 20

Table 2. Grain yield of Melkasa2 and checks in on-farm demonstration plots, 2005.

Location				Productivity (t ha^{-1})		
District	*Kebele*	Parameter	Number of participants	Melkasa2	A511	Local
Boset	Dongore Tiyo	Average	3	5.2	4.8	2.9
		SD		1.0	0.4	2.0
	Dongore Furda	Average	2	5.6	4.9	3.3
		SD		1.5	1.0	1.1
Adami tulu	Anano Shisho	Average	2	5.0	3.5	–
		SD		1.4	1.1	–
Total average		Average	7	5.3	4.5	2.2
		SD	7	1.3	0.7	1.2
Percent yield advantage of Melkasa2	Over A511		7		117.9	
	Over Local		7		240.2	

SD = standard deviation.

Table 3. Comparative yield advantage of Melkasa3 over A511 in farmers' fields, 2006.

Kebele	Number of farmers	Parameter	Productivity (t ha^{-1}) Melkasa3	Local	Percent yield advantage (Melkasa3/Local)
Dogore Furda	4	Average	3.5	3.0	17
		SD	0.6	0.2	
Dogore Tiyo	5	Average	3.0	2.5	18
		SD	0.5	0.2	
Dangore Chale	4	Average	3.2	2.7	19
		SD	0.4	0.2	
Awash Melkasa	7	Average	2.3	1.5	51
Anano Shisho	4	Average	4.3	3.2	33
		SD	1.9	1.2	
Tuchi Sumayan	3	Average	2.9	2.4	22
		SD	1.0	0.4	
Total	27		3.1	2.6	21
SD			1.0	0.7	–

SD = standard deviation.

participating farmers applied fertilizer to their local maize. On average, Melkasa2 and Melkasa3 gave one cob per plant while the local variety gave 0.83 cobs per plant, which indicates the existence of a considerable number of barren plants in the local variety. The local variety was the tallest in plant height and was found to be susceptible to lodging (data not shown).

Spacing between maize plants and plant population at maturity

In view of the observations of differences between plant populations on farmers' fields and recommended practice in the previous years, the spacing between plants and between rows was measured at harvest to estimate the plant population density in 2007. From the data collected, wide spacing between plants and narrow spacing between rows was recorded. The recommended plant and row spacing, 25 cm × 75 cm (5.33 plant/m^2) was found to be higher than the one used by farmers, 54 cm × 46 cm (4.08 plant/m^2). The farmers' plant spacing was dictated by the limits of what their traditional ploughs could make, hence it was concluded that there was a need for further studies to determine the appropriate plant spacing. Moreover, from the field observation, besides the seed quality, the depth at which the seed was placed at planting may have an effect on germination and thus on plant population density, hence, the need for further research attention on plant spacing by researchers as well as extension agents.

In addition to yield and agronomic data, farmers' opinion on varietal preference was collected from participating farmers during variety demonstration. The results showed that Melkasa2 was preferred by most of the farmers for its high yield, earliness and taller plant height over Melkasa3. The tall variety was preferred for animal forage and construction purposes. Melkasa3 received the second rank for its earliness and high grain yield (Table 4).

The improved varieties gave higher grain yield than the local variety at all locations. Generally, from demonstrations conducted at 20 sites average grain yields of 4.0, 3.7, 2.6 t ha^{-1} were obtained for Melkasa2, Melkasa3 and the local variety, respectively (Table 5). However, there was a considerable grain yield difference among the varieties across locations. The maximum grain yield potential for both the improved varieties was recorded in the Adamitulu district (Anano Shisho *kebele*) where the topography was flat and farmers' field management was better. At Anano Shisho the farmers practiced hoeing/cultivation (twice) and timely weeding as compared to the other locations. The lowest grain yield was observed at Awash Melakssa of Adama district for all varieties. This might be attributed to late planting (second week of June), no hoeing/cultivation and erratic rainfall.

Table 4. Farmers' preference for different varieties, 2007.

Variety	Reasons for variety preferences			Total[†]
	High yield	Early	Tall stalk	
Melkasa2	10	2	2	10
Melkasa3	5	5	–	5
A511	1	–	1	1
Total	16	7	7	16

[†] Not summed horizontally since the criteria do not exclude one another and there are famers who preferred a variety for more than one criterion. For example, Melkasa2 was liked by ten farmers; all of them preferred it for its high grain yield while two each preferred the same variety from the same group for earliness and tall stalk in addition to yield.

Table 5. Grain yield of improved maize varieties under improved management and local varieties under farmers' practices, 2007.

District	No. of farmers	parameter	Productivity (t ha^{-1})		Local	% Yield advantage over local check	
			Melkkasa2	Melkasa3		Melkasa2	Melkasa3
Adama	8	Average	3.1	3.2	2.4	30	31
		Max	5.0	5.0	5.0		
		Min	2.1	1.4	0.7		
		SD	1.0	1.2	1.7		
Adami tulu	4	Average	5.6	4.5	2.6	183	74
		Max	5.6	4.5	3.0		
		Min	4.7	3.9	2.4		
		SD	0.5	0.4	0.3		
Boset	8	Average	4.1	3.8	2.9	44	33
		Max	7.0	7.0	6.4		
		Min	1.9	1.7	0.7		
		SD	1.9	2.0	2.0		
Total	20	Average	4.0	3.7	2.6	53	41
		Max	8.7	7.3	6.4		
		Min	1.9	1.4	0.7		
		SD	1.7	1.6	1.5		

SD = standard deviation.

Economic analysis of improved and local practices

In addition to biological performance and agronomic management evaluation of the varieties under demonstration plots, the economics of maize production was analyzed to assess the profitability of new varieties and management practices over existing practices (local variety and farmers' practice). The important variables considered were variety (local vs. improved), fertilizer used, and other management practices. In the farmers' practice, farmers employed similar management practices to that of improved varieties other than variety and fertilizer rate. In the local practice, few farmers applied fertilizer. For the new varieties 100 kg ha^{-1} DAP (Diammonium phosphate) and 50 kg ha^{-1} urea were applied while in farmers' practice, the fertilizer rate used ranged from zero to the recommended levels. Maize production input costs were used for economic profitability analysis for each farmer and the summary is presented in Table 6. In the economic analysis, labor and fertilizer were considered the most important economic variables since most farmers consider the new varieties as input intensive (i.e., high demand for labor and fertilizer). As it is indicated in Table 6, a farmer could gain an additional 1933 and 1322 Birr per hectare, by applying an additional expense for labor and fertilizer, and would obtain a marginal rate of return of 183% and 130% from Melkasa2 and Melkasa3, respectively (Table 6).

In 2008, an on-farm demonstration with the established farmer groups was conducted to compare the quality protein maize (Melkasa6Q) with Melkasa2. As it can be observed from Table 7, the performance of the varieties differs across farmers' fields. The highest grain yield was recorded in the Boset district while the lowest yield was observed in the Adama district. Across locations mean grain yield was 3.6 and 2.8 t ha^{-1} for Mekassa6Q and Melkasa2, respectively. Such a poor performance of Melkasa2 was largely due to poor field management (no thinning), flood damage (Adama district), dry soil moisture conditions (Admitulu district) and prolonged dry spells at emergency (Table 7).

Given its earlier maturity, Melkasa6Q must have taken advantage of the moisture stress to outperform Melkasa2 during this particular year. However, the performance in the following two years (2009 and

Table 6. Marginal rate of return between improved maize package and farmers' practices, 2007.

Treatment	Average yield (t ha^{-1})	Gross income (Birr†)	Fertilizer cost (Birr ha^{-1})	Labor cost (Birr ha^{-1})	Gross margin (Birr)	Marginal income	Marginal cost	Marginal rate of return (%)
Local (control)	2.6	5,943	97	928	4,918	–	–	–
Melkasa2	4.0	8,927	576	1,500	6,851	1,933	1,051	183
Melkasa3	3.7	8,277	576	1,461	6,240	1,322	1,012	130

† 1 USD = approx. 9 Birr (in 2007).

Table 7. Yield of on-farm maize variety (Melkasa6Q) demonstration, 2008.

District	Site (*Kebele*)	Demostration area (ha)		Productivity (t ha^{-1})	
		Melkasa2	Melkasa6Q	Melkasa2	Melkasa6Q
Adama	Adulala Hatie Haroreti	0.1	0.1	3.5	4.0
	Adulala Hatie Haroreti	0.1	0.1	1.3	2.2
	Adulala Hatie Haroreti	0.2	0.1	1.3	1.3
Average		0.1	0.1	2.1	2.5
Boset	Denore Furda	0.2	0.1	2.5	4.4
	Denore Furda	0.2	0.2	2.5	5.6
	Denore Furda	0.1	0.1	4.0	4.8
	Dengore Tiyo	0.1	0.1	2.2	2.7
	Dengore Tiyo	0.2	0.1	2.4	4.0
	Dengore Tiyo	0.2	0.1	2.7	2.8
Average		0.2	0.1	2.7	4.1
Adamitulu	Aneno Shisho	0.1	0.1	1.8	1.1
	Aneno Shisho	0.1	0.1	3.0	4.4
	Aneno Shisho	0.1	0.1	5.5	4.2
	Aneno Shisho	0.1	0.1	4.0	5.2
Average		0.1	0.1	3.6	3.7
Mean		0.1	0.1	2.8	3.5

2010) clearly indicated that Melkasa2 consistently remained superior to Melkasa6Q and other drought tolerant maize varieties (Table 9).

The demonstration plot in the Adama District was affected by armyworm while an early stage moisture stress was observed at Adama and Adamitulu that contributed to low plant population density. At the maturity stage, different farmer groups including the participating and surrounding farmers carried out their own assessment of Melkasa2 and the new variety Melkasa6Q. A considerable number of famers (89) attended the field evaluation. Both men and women of all age groups attended and their assessment of the varieties is summarized in Table 9.

Farmers preferred Melkasa6Q to Melkasa2 mainly for its earliness, comparable grain yield, larger cob size and well-filled grain in addition to the quality of its protein (what farmers call '*bitaamin*'). They also indicated the compatibility of the variety with haricot bean in intercropping. However, Melkasa2 was also chosen for its productivity (from previous years' experience) and higher biomass for cattle feed. Some of these farmers' observations, for example for intercropping, nonetheless, would require further scientific investigation.

Table 8. Farmers' preference score between Melkasa2 and Melkasa6Q, 2008.

Location	Melkasa2	Melkasa6Q	Both	Total
Adama (Adulala Hatie Haroreti)	2	1	12	15
Boset (Dongor Tiyo & Dongore Furda)	2	16	2	20
Adamitulu (Anano Shisho)	7	37	10	54
Total	11	54	24	89
% preferred	12	61	27	100

Farmers also indicated that the presence of different maturity groups, as an option, would be useful in widening their decision range pertaining to the changing climatic conditions. Women farmers pointed out that early maturity was preferred since the maize could be consumed as green cobs during seasons of food deficit while the late maturing ones could be consumed as grain. Accordingly, both early and late maturing varieties could supplement each other in improving household food availability. Considerable numbers of farmers (27%) still wanted to produce Melkasa2 and the Melkasa6Q (QPM) variety simultaneously (Table 8).

During 2009 and 2010 a new variety, Melkasa4, was included in the on-farm demonstration in addition to the previously farmer-preferred varieties, *viz*., Melkasa2 and Melkasa6Q. The new variety, Melkasa4 was said to be earlier in maturity than Melkasa6Q and as good in grain yield as Melkasa2. However, the two year result suggested that Melkasa4 had comparable grain yield with Melkasa6Q but was outperformed by Melkasa2 (Table 9). In addition, from farmers and from field observations during the two years, it was realized that Melkasa4 was not as early in maturity as Melkasa6Q. Consequently, in the majority of cases the farmers' preference remained with Melkasa2 and Melkasa6Q for similar reasons as mentioned previously.

Promotion of farmer preferred maize varieties in the central rift valley

As a follow up to the result of the on-farm variety evaluation and demonstration activities, modest efforts were made to boost the awareness, as well as access, to the new drought tolerant maize varieties by the surrounding farmers. Accordingly, community-based seed production as well as training activities were carried out together with different partners, *viz.*, agricultural offices, NGOs and local seed enterprises. These activities were implemented since 2005 when farmers began to widely demonstrate their interest in the new varieties. To

Table 9. Grain yield of Melkasa2, Melkasa4 and Melkasa6Q in field demonstrations conducted in 2009 and 2010.

	Mean yield (t ha^{-1})								
	2009			2010			Combined means yield (t ha^{-1}) (2009 and 2010)		
District	Melkasa2	Melkasa6Q	Melkasa4	Melkasa2	Melkasa6Q	Melkasa4	Melkasa2	Melkasa6Q	Melkasa4
Dugda	4.8 (6)	4.6 (6)	3.8 (3)	5.3 (5)	4.9 (5)	5.4 (2)	5.1	4.7	4.6
Adamitul	4.9 (8)	4.5 (8)	3.0 (4)	4.1 (5)	3.1 (5)	2.84 (3)	4.5	3.8	2.9
Bora	5.1 (4)	4.7 (4)	6.7 (1)	2.7 (2)	2.3 (2)	2.0 (1)	3.	3.5	4.3
Adama	7.1 (1)	5.7 (1)	4.6 (1)	4.2 (3)	2.6 (3)	3.3 (1)	5.7	4.1	3.9
Boset	–	–	–	5.5 (5)	4.6 (5)	4.0 (3)	–	–	–
Shala	–	–	–	2.4 (5)	2.4 (4)	3.1 (3)	–	–	–
Grand Mean	5.0 (19)	4.6 (19)	3.9 (9)	4.0 (25)	3.3 (24)	3.4 (13)	4.8	4.0	4.0

Data in brackets indicate the number of participating farmers.

enhance the adoption and utilization of the new quality protein maize variety, Melkasa6Q, different promotion techniques were also used.

In response to increasing demand for the new drought tolerant maize varieties, an attempt was made to deliver the seed by way of localized seed production with FRGs and the surrounding community. This served the purpose of making seed available locally and it improved seed accessibility by many small scale farmers (Table 10). In addition to the skill gained in seed production, the seed producing farmers also obtained additional income through sales (of the seed to local farmers and seed enterprises). The seed produced was, in general, disseminated to many other small-scale farmers via exchange, sales, gifts, and borrowing. Furthermore, the partnership formed with Oromia Seed Enterprise as well as respective agricultural offices and NGOs was instrumental in ensuring the seed market as well as sustainability of farmer-based maize seed production.

Moreover, through popularization, as a means to widen the base of awareness of the production technologies, hundreds of farmers were reached with improved varieties (Table 11). The seed were disseminated and shared among farmers through different locally established social networks. The use as well as proper understanding of these networks remains critical in speeding up the technology dissemination.

Training was another important tool utilized to promote and enhance the adoption of improved maize varieties. Annually, all participating farmers as well as extension agents in respective districts were given year-round training on characteristics of the varieties and their management practices, and leaflets as well as handouts were also distributed.

The introduction of new varieties such as Melkasa6Q with only focus on production aspects does not lead to the exploitation of their full potential. For this reason, training of farmers, development agents, small restaurant owners, home economists, and health extension workers was organized. The training was arranged to demonstrate different traditional food preparation options in order to improve consumption and enhance nutrition of the community. Accordingly, trainees were given hands-on training in the preparation of various local and new food recipes (Fig. 1) from maize (Table 12).

Figure 1. Various local and new food recipes

Table 10. Farmer-based seed production of farmer-preferred maize varieties.

Year	Varieties	Districts addressed	Area covered in ha (no. participant farmers)	Seed produced (t)
2007	Melkasa2	Adamitulu Boset Adama	3.1 (8)	16.1
2008	Melkasa2	Adam, Boset Adamitulu	10.5 (10)	54.5
2009	Melkasa2 Melkas6Q	Adamitulu Bora	13.5 (55)	22.0
2010	Melkasa2 Melkasa6Q	Adama, Boset, Bora, Dugda Adamitulu, Shala	13.0 (53)	39.3

Table 11. Popularization of farmer-preferred drought tolerant maize varieties.

Year	Varieties	Districts addressed	Number of farmers reached (area covered in ha)
2007	Melkasa2	Adamitulu, Boset	12 (6.0)
2008	Melkasa2	Adama, Adamitulu, Bora, Boset, Dugda	220 (69.6)
2009	Melkasa2	Adama, Adamitulu, Bora, Boset, Dugda, Shala	115
2010	Melkasa2 Melkasa6Q	Adama, Boset, Bora, Dugda Adamitulu, Shala	42 (10.2)

Table 12. Composition and number of trainees who attended demonstrations of maize traditional food preparations in 2008.

Trainee Types	Male	Female	Sub-total
Farmers	24	45	69
Development agents	5	3	8
Home agents	–	2	2
Health extension workers	–	1	1
Small restaurant owners	–	11	11
Total	29	62	91

Western and Hawassa areas

The western part of Ethiopia is one of the dominant maize-based farming systems in the country. Owing to its potential, a number of improved maize varieties have been released in the zone by the national maize research program. These varieties were demonstrated and promoted to farmers through on-farm demonstration and popularization activities since 2003.

On farm demonstration of improved hybrid maize varieties (2003–2005)

During 2003 and up until 2005, improved maize varieties (BHQP542, Gibe1 and BH670) with their production packages were demonstrated on 400 farmers' fields side by side with the local variety. All three varieties (BHQP542, Gibe1 and BH670) outperformed the local varieties with additional yield advantages of 76.74, 66.67 and 140%, respectively (Table 13).

Farmers appreciated the bread and '*Injera*' quality of BHQP542 maize as compared with the local and improved conventional maize varieties. From farmers' assessment, Gibe1 was an early maturing composite that farmers liked particularly during the short rainy season, and it was also a lodging tolerant variety because of its intermediate height. The drawback with this variety (as per farmers' perception) was that it naturally opened its ear tips at maturity, and therefore, this phenomenon paved the way for the entry of rain water into the cob (before harvest), leading to ear rot and grain yield loss. The high yield advantage of BH670 was partly due to its lateness in maturity as compared with the other improved varieties, which enabled it to exploit the long rainy season in the western part of the country.

During 2007, an on-farm variety verification was conducted at three locations *viz*. Bako, Hawassa and Jimma to compare a new yellow quality protein maize variety (BHQPY545) with previously released QPM varieties (BHQP542 and a non-QPM BH540). The results indicated that the new variety out-yielded the two checks by 19 and 8%, respectively (Table 14).

Promotion of farmer-preferred maize varieties

BHQPY545 was promoted on farmers' fields during 2008–2009 to increase the level of awareness as well as use by target communities. The good news about this variety is that it has double advantages for the poor farmers whose staple food is maize in that it is QPM (contains high level of lysine and tryptophan) and possesses some good levels of pro-vitamin A in addition to its superior grain yield. It is in high demand

Table 13. On-farm grain yield performance of hybrid maize varieties during 2003, 2004 and 2005 cropping seasons along with local varieties (East Wollega, West Wollega and West Shewa).

Maize variety	Number of participating farmers	Average yield (t ha^{-1})	% Yield increment over local check
BHQP542	200	4.6	76.7
Local check		2.6	
Gibe1	100	3.5	66.7
Local check		2.1	
BH670	100	5.5	140.0
Local check		2.3	

Table 14. Grain yield (t ha^{-1}) of the yellow QPM variety (BHQPY545) and two checks (VVT, 2007).

	Bako			Jimma			
Variety	On-farm (Anno)	On-farm (Shoboka)	Hawassa On-farm	On-farm (Kersa)	On-farm (Nada)	Overall mean	% Yield advantage over check
BHQPY545	5.6	5.9	8.1	5.9	6.1	6.3	
BHQP542	5.3	5.3	5.4	5.3	5.4	5.3	19
BH540	5.3	4.9	8.8	4.9	5.4	5.9	8

by poultry farms and food processing industries. In addition to the previous years' demonstration and popularization, all other recommended maize varieties were demonstrated to farmers (Table 15). BH543 was also preferred among the seed producers because the seed parent is a single cross and had higher grain yield than the seed parent of BH540.

Central Highlands

In partnership with respective agricultural offices, NGOs and other partners, the highland maize research program conducted extensive variety demonstration and promotion activities using farmer-preferred maize varieties around Ambo, Holetta and Gurage zone from 2005 to 2009. More than 1300 farmers were involved as a host and many other surrounding farmers were also reached through field days organized around the demonstration plots in the areas (Table 16).

South-western Ethiopia

South-western Ethiopia is another potential maize producing/farming system which includes Jima and Illubabora areas and is characterized by a long rainy season. Maize production is constrained by various abiotic and biotic factors, leaf diseases being the most important ones. In addition to the nationally released varieties for mid-altitude areas, a late maturing and foliar disease tolerant OPV (Morka), improved UCB, was released in 2008. The performance of Morka at two on-station and four on-farm sites in Jimma (*Kersa*-1 and *Kersa*-2) and Illubabora (*Gai* and *Sor*) zones showed a yield advantage of 21, 61 and 46% over Kuleni, Gibe1 and UCB-original, respectively (Table 17). The plant and ear heights of Morka were also significantly reduced by about 24.8 and 14.2%, respectively, over the UCB–original line (data not shown). This reduction in plant and ear heights was a very important achievement towards overcoming

Table 15. Location and the number of farmers who participated in the promotion of the farmer preferred maize varieties in 2008 and 2009.

Cropping season	Demonstrated varieties	Zone	District	Village	No. of participating farmers
2008	BH543,	East	Sibu Sire	Cheri	107
	BHQPY545	Wollega	Gobu Sayo	Anno	93
	and all the		Bako Tibe	Bako	78
	other	West		Shoboka	90
	varieties	Shewa	Ilu Galan	Sayo	104
				Ijaji	113
			Sibu Sire	Chingi	60
2009	BH543,	East		Jalale	87
	BHQPY545	Wollega	Gobu Sayo	Ongobo dambi	35
	and all the other			Darartu safara	39
	varieties		Gudeya Bila	Bila	35
		West	Bako Tibe	Tulu sangota	107
		Shewa		Oda Haro	63
			Ilu Galan	Jato dirki	46
				Sibabiche	62

Table 16. Number of farmers who participated in the demonstration and popularization of highland maize varieties in different areas, 2005-2009

Variety	Location	Number of participants by year					Total number of farmers
		2005	2006	2007	2008	2009	
Arganne	Ambo,	12	75	310	333		730
	Holetta,			20	80		100
	Gurage Zone			80	80		160
Hora	Ambo	8	60				68
	Holetta			20	80		100
	Gurage Zone			128	64		192
Wenchi	Ambo				1	15	15
Jibat	Ambo					3	3
Total							1,368

Table 17. Mean grain yield of Morka and other maize varieties evaluated at Melko, Metu, Sor, Gai, Kersa-1 and Kersa-2 in 2007.

Varieties	Grain yield ($t\ ha^{-1}$)	% Yield advantage of Morka over checks
Morka	6.2	
Kuleni	5.1	21
Gibe 1	3.8	61
UCB-original	4.2	46

the problem of lodging commonly observed in the UCB-original. Due to these and other reasons, Morka was adopted by farmers in Jimma and Illubabora zones. Morka is late as compared to Kuleni and Gibe1; therefore, it should be planted only in areas where the rainy season is long similar to that of the south western part of Ethiopia.

Conclusions and Recommendations

The maize technology demonstration and promotion carried out in the different farming systems led to important lessons and research directions that can be taken up by different actors in the production and utilization system. The OPVs with important traits of drought tolerance coupled with higher productivity (Melkasa2) and QPM (Melkasa6Q) proved their value before farmers' important criteria, particularly in the central rift valley where moisture is an important limiting factor to production. Melkasa3 and Melkasa4, though their yield performance was as good as Melkasa6Q (which basically had additional nutritive value- quality protein) and slightly lower than Melkasa2, can remain as technological options to the farmers. The economic merit of producing the improved maize variety (Melkasa2) over the local one is also an incentive for the farmers to invest in the production of this variety. Moreover, the effort made to improve local availability of farmer preferred varieties through farmer based seed production in partnership with other important actors, *viz.*, Oromia Seed Enterprise and respective agricultural offices and NGOs, was an important step towards realizing and enhancing localized supply of improved maize varieties. Yet, there needs to be more attention given to improving the seed marketing against the grain market, which at times siphons off all the seed produced for its competitive price advantage.

Generally, the two varieties, Melkasa6Q and Melkasa2, with their superior yield advantage and quality protein (the former) need to be widely promoted by research, extension departments, seed enterprises and farmers' cooperative unions to provide production options in improving drought tolerant maize productivity in the central rift valley. From the then on-farm activity, it was also observed that research needs to revise the recommended row spacing or redesign best farm implementation because existing farmers' ploughs open a narrower space between furrows than the research recommends (75 cm between rows). Moreover, research needs to devise a mechanism to provide the best alternatives for farmers to pursue row planting of maize, or farmers may be forced to resort to broadcasting due to labor shortage. There is also a need to identify optimum planting depth as it has affected germination. These all definitely have an implication on the productivity by way of affecting the optimum plant population.

Given the superior yield performance of BHQPY545, BHQP542, BH670 and Gibe1 over the local check as well as farmers' positive attitudes towards these improved varieties, it is important to carry out wider popularization and dissemination through the extension system to improve productivity as well as the nutritional status of farming communities in the western maize production areas of East and West Wollega as well as West Shewa areas. The promotion efforts underway (for the improved maize varieties, *viz.* Arganne, Hora, Wenchi and Jibat) in the central highland of Ethiopia need to be carried out aggressively and must be linked with the existing extension system for maximum reach. Likewise, the superior advanced version of UCB C_O maize variety, Morka, developed for the south western target production zones should also be widely promoted in a more coordinated way with the formal extension system.

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Historical Perspectives of Technology Transfer in Ethiopia: Experience of the Ministry of Agriculture

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Introduction

Maize has been cultivated in Ethiopia for the last 500 years (Haffangel, 1961). It grows in all parts of the country and is second only to *tef* in area coverage. Among the major cereal crops in Ethiopia, it ranks first in volume of production and yield per unit area. The major producing areas are southern, western, south-western, and eastern parts of the country. Given its potential productivity, maize is one of the strategic crops for meeting the food security target of the government of Ethiopia. In the past four to five decades, dissemination of improved technologies of crops including maize has passed through different extension approaches, each having its own philosophy and technological packages.

Extension is a non-formal education. Historically, it was designed to provide people outside the formal education system with 'proven' skills and practices. Over time its importance in promoting science-based practices has increased. Owing to this feature, it was given an important role in agricultural and rural development processes in Europe and North America. Extension spread to other parts of the world during the colonial era and through economic and financial assistance programs after World War II (Swanson, 1984).

Extension as an educational process has been exploited in many countries. Huge financial and material resources have been invested to undertake extension in both developed and developing countries. The driving force for its acceptance is the theoretical background of extension that is invariably attractive to policy makers worldwide. The theory underpinning extension in this regard is the 'diffusion theory', with its off-shoot of 'transfer of technology' (TOT). This theory has made a substantial contribution to increased food production in several countries, including developing countries. The famous 'Green Revolution' in Asia was guided by this theory. In spite of these achievements, the theory has some critical limitations (Chambers and Jiggins, 1987), which are summarized below.

Assumptions and Limitations of Diffusion Theory

The model is sequentially linked, i.e., a linear model. Technology from agricultural research is transferred to farmers through extension agents whereby farmers are expected to use it. Depending on the specific extension approach adopted by an extension system, a technology may pass through different entities. For instance, a contact farmer may share a technology he receives from an extension agent with fellow farmers. The feedback side of the model is inherently weak, as extension agents and farmers are not involved in relevant processes in the technology generation. Technology is generated in research institutions that are spatially placed away from farmers' field activities. The model also has an implication on the mode of organization of agricultural research, extension and their linkage.

Technology is often perceived as a product and, therefore, packaged for delivery through the extension agent to farmers. Technologies developed on reductionist assumption of farm realities are translated to commodity knowledge. This mechanism has proved successful for technologies such as improved seeds, fertilizers, pesticides, herbicides, etc., where social, institutional and infrastructural conditions are fulfilled. Generally, the model assumes that technologies developed by research are relevant and have a chance for further diffusion.

The diffusion theory model is reinforced by market forces and several stakeholders who have interest in the process. These include: policy makers, merchants, banks, input suppliers, and transport companies. The diffusion model has, however, little relevance when it comes to serving resource-poor farmers, natural resource management, sustainable development, and ecological agriculture.

General Overview of Past and Present Extension Approaches in Ethiopia

The formal beginning of public agricultural research and extension in Ethiopia can be traced to the initiation and establishment of agricultural service institutions in the late 1940s and early 1950s. Such service institutions include the Ambo Agricultural High School (1947), The Jimma Agricultural and Technical School (1952) and the Alemaya College of Agriculture (now Haramaya University) (1954). The latter two institutions enjoyed substantial external support from the United States Agency for International Development (USAID) up to 1968 through a bilateral agreement reached between the governments of the USA and Ethiopia.

The then Alemaya College of Agriculture was modeled after the USA land grant college system, where agricultural training, research and extension are fully integrated in one institution. In order to fully expedite its triple mandates, the Alemaya College of Agriculture, in addition to its research facilities at Jimma and Haramaya, opened a research station at Debre Zeit in 1955. The station was mainly intended to cater for the central highlands of Ethiopia and the staff located at the station were to exclusively focus on research. In 1963, under the scheme of indigenization, the college became part of the Haile Selasie I University (now Addis Ababa University), and its nationwide mandate of agricultural extension was transferred to the Ministry of Agriculture (MoA). Being responsible for extension, the MoA is the only public institution that has a direct link with the farmer. Over the years, the MoA has followed different approaches to reach the farmer (Table 1).

In the 1960s and early 1970s intensive regional agricultural development projects were launched. The first series of package programs were the so-called maximum package programs (MPPI). These included the establishment of Chilalo Agricultural Development Unit (CADU) in 1967, through the Swedish International Support (SIDA), the Wollaita Agricultural Development Unit (WADU) in 1971 through the World Bank support and the Ada District Development Project (ADDP) in 1971, through the USAID support. These projects focused on providing comprehensive support including infrastructure and technological input to the specific region where the projects were located. Their coverage was, therefore, limited to the area where the projects were located. This naturally caused regional economic inequalities. Because of the high investment required and the need for skilled staff, it was found to be difficult to replicate the intensive MPPI project across the country. Thus a more comprehensive MPPII of the Extension and Program Implementation Development (EPID) was created within the MoA in 1971 (Amare, 1977). All the intensive regional development projects like CADU, WADU and ADDP were included under the EPID program as part of national extension network. EPID's programs were assisted by the Food and Agriculture Organization's (FAO's) Freedom From Hunger Campaign (FFAC) fertilizer trials and its major focus was on fertilizer followed by improved seeds and pesticides (Amare, 1977). The richer farmers benefited from the regional projects and the MPPII of EPID. These approaches also helped the development and expansion of commercial farms prior to the 1974 revolution (Amare, 1977). The majority of the farmers were not the beneficiaries of these projects, perhaps with the exception of model farmers and those along the roadsides in the case of MPPII.

As a follow-up of MPPII, the Peasant Agricultural Development Project (PADEP) was launched in 1983. PADEP was intended to enhance input distribution, promote the role of cooperatives in rural development, improve linkage between research and extension, and improve the performance of extension based on Training and Visit (T & V) concept. The three key elements of the T & V approach were: promoting effective communication with farmers; strengthening linkage between research and extension; and improving the performance of extension based on training and visits. In the Ethiopian context, the T & V system narrowed the communication gap between the farmer and the extension agent, but the linkage between research and extension remained unchanged. The training of extension agents on a bi-weekly basis was also boring and redundant (Alemneh, 1989). The system was not supported by an effective and strong technology generating network.

Table 1. Evolution of rural development and extension approaches.

Period	Rural development approach	Extension approach
1930–1950	Some activities by religious donors and national institutions with mandates for the agricultural sector	–
1954	Not formalized	Alemaya College of Agriculture Approach (Land-Grant College)
1958	Community development approach	GAEA
1968	Maximum approach (CADU, WADU, ADDP)	GAEA
1971	Minimum package	GAEA
1986	PADEP	T&V
1993	PADEP	SG2000
1994	PADEP	PADETS + SG2000
1995	Agricultural Development-Led Industrialization	PADETS + Modified SG2000

CADU = Agricultural Development Unit, WADU = Wollaita Agricultural Development Unit, ADDP = Ada District Development Project, PADEP = Peasant Agricultural Development Project, T&V = Training and Visit, PADETS = Participatory Demonstration and Extension Training System, GAEA = General Agricultural Extension Approach, SG2000 = Sasakawa Global 2000.

In general, extension approaches prior to 1993 shared some common shortcomings. These included: inappropriate choice of extension approaches and strategies, lack of extension professionalism and relevant agricultural technologies, low research and extension linkages, and poor participation of farmers in generation and utilization of technologies. These situations led the government to reform the extension service to assist economic development policy of the country.

Beginning from 1993, a major influence in agricultural extension has been the Sasakawa Global-2000 (SG2000) program which promoted a credit-supported technology package of seeds and fertilizers. This strategy of 'aggressive technology transfer' (Borlaug and Dowswell, 1994) was taken up by the Ministry of Agriculture as part of a national extension strategy, known as the Participatory Demonstration and Extension Training System (PADETS), which combined a training, visit and demonstration plot-based extension system with the SG2000 fertilizer and seed credit package. Currently, extension strategy is determined by the National Extension Intervention Program (NEIP), which aims to ensure food self-sufficiency, while the present approach, known as the Participatory Demonstration and Extension Training System (PADETS), combines elements of the previous T & V system with the SG2000 approach.

According to Habtemariam (1997), the NEIP was an emergency strategy of the government, developed on the basis of the experience of SG2000 in Ethiopia, which had attracted the attention of policy makers through a well-organized publicity campaign. National research and extension institutions were involved in SG2000 activities, which began in 1993 with an assessment of the technologies available in the country. Technology packages for maize and wheat were then developed and evaluated with 160 farmers in *woredas* (districts) in Oromia and the southern regions, and in demonstrations by agricultural officers and farmers working with material and technical support from SG2000. In 1994, the field program broadened to include sorghum and *tef*, and the number of farmers involved rose to 1600. The good weather in 1995 helped to produce impressive grain yields; persuading the government that self-sufficiency in food could be achieved with the SG2000 approach and it was adopted that year as the foundation for NEIP. The plan was for NEIP to cover 35,000 farmers, while SG2000 continued to work with 3,500 producers.

On the basis of the existing extension strategy (NEIP), Ibrahim and Tamene (1999) reported an average maize grain yield range of 3.68 t ha^{-1} in 1995 to 5.76 t ha^{-1} in 1999. Similarly, Takele (2002) reported that an average maize grain yield of 4.0 to 5.0 t ha^{-1} was common in fields of farmers who participated in the extension program. On the other hand, CSA's (2010) pre-harvest maize yield assessment reported the current national average yield as 2.3 t ha^{-1}.

In 1996 the government organized a national agriculture workshop at Jimma, which was known as the 'Jimma Conference', chaired by the Prime Minister, and attended by many people from council offices, the Bureau of Agriculture, SG2000 and others. The main theme of the workshop was how to expand the SG2000 experience within the regular regional extension programs. It was decided that the SG2000 approach should be scaled up, with a ten-fold increase in demonstrations over the next year, targeting 350,000 farmers who would plant a NEIP demonstration plot in all regions. It was also decided to include other agricultural technology packages such as livestock, high value crops and post-harvest handling.

According to an extension expert in the regional Bureau of Agriculture, the main strength of the NEIP or PADETS approach is that *"it considers three basic elements of an extension system, namely a package of technologies, credit and communication".* These three elements involve many actors, such as the input co-ordination unit, the cooperative office, state council offices, credit institutions and private sector suppliers of inputs such as fertilizers, seeds and agro-chemicals. One observer, however, commented that PADETS is an excellent extension system in principle, but that it has been distorted by the manner in which it has been implemented.

The SG2000 program is a collaboration between the Sasakawa Africa Association and the Carter Center's Global 2000. Operative in over ten African countries, this program aims to bring 'science-based crop production methods to the small-scale farms of sub-Saharan Africa' by disseminating proven technologies. SG2000 emphasizes the primary role of mineral fertilizers in improving soil fertility and agricultural production. However, the program is not without its shortcomings.

There was considerable debate over the best way to set up a credit system for the program. Farmers cannot borrow directly from banks because they have no conventional forms of collateral, so it was decided that the regional council offices would secure credit from the banks and channel it into the co-operatives at zonal and *woreda* council offices. Farmers involved in the extension program would then receive credit in kind (seeds, mineral fertilizers or other agro-chemicals) from the agricultural offices through these or co-operatives and repay the loan after the harvest. There are various problems associated with this system. The agricultural offices and co-operatives are pressed for timely loan repayments by the regional and zonal offices, which use their yearly budgets as collateral for the bank loans, while farmers are pushing to have their debts rescheduled after bad harvests so that they do not have to sell their livestock to pay off their loans.

Development agents and extension workers also complain that being responsible for collecting repayments compromises their role as extension educators, as farmers are unwilling to take their advice after they have been pressured to repay their loans. The extraordinary speed of the program may hamper follow-up and technical support. Extension workers who are said to assist on average 60–70 farmers may not be in a position to adequately assist new participants. Information distortion among participating farmers should not be underestimated. It has to be noted that there are wide variations among Regional States with respect to number, qualification and experience of extension agents. Increasing the number of less qualified inexperienced extension agents is of less use as degree of complexity of extension demonstration packages increases. The SG2000 approach appears over ambitious and inappropriate under the prevailing socio-economic conditions, which include poorly developed input supply systems as well as transport and market services. For example, devaluation of the Ethiopian Birr in 1992 and rising world prices increased the price of mineral fertilizer. Moreover, abolishment of the previous fertilizer subsidy in 1996 made financial viability of fertilizer and high-yielding seed packages burdensome for most farmers (Belshaw, 1997).

Mineral fertilizer use is seen by Ethiopian officials as the easiest way to maintain or improve soil fertility and increase productivity. All extension initiatives have focused on the dissemination of the same recommended rate of fertilizer to farmers under all kinds of socio-economic conditions and agro-ecological zones. No nationwide effort was made to encourage farmers to use locally available sources of nutrients like manure more efficiently or to teach them to use compost manure.

Despite all past extension initiatives, 85% of Ethiopian farmers did not use any fertilizers at all, while others used them at levels significantly below the recommended rates. The complex nature of the soil fertility problem and the prevailing diverse farming system conditions in the country was not appreciated sufficiently at policy and project design levels (NFIU/MoA, 1995). Notwithstanding the relevance of the package approach to some areas of the country, the same approach is not feasible at the national level. The complexities of social and technological contexts seem to be underestimated. Therefore, their application according to differences in farm size is generally negligible. The program lacks diversity of approaches in its current form, where only the TOT model is applied. As mentioned earlier, the methodology of the program focuses more on the TOT model rather than on an adaptive technology generation and utilization.

Conclusion

So far, the extension systems in the country have been applying limited tools used for the transfer of technology. The tradition of extension in the past and the current intensification of the TOT approach make it less responsive to the requirements of sustainable agriculture. The role of extension should go beyond passing on information from researchers to farmers. The present level of land degradation in Ethiopia urgently requires the facilitation of a platform for sustainability. Approaches which further encourage farmers' participation to decide what they need in light of their own environment rather than making such decisions through extension and research is essential.

Ethiopia has shown dramatic increases in adoption since 1992 (when almost no farmers were growing improved maize varieties) due to the introduction of a new extension system supported by the SG2000. Extension is clearly the variable that is highly correlated with the use of improved technologies. There continues to be an important role for extension services to disseminate information on new varieties and how to manage them. It is not always clear, however, what the extension variable is actually capturing. It may be related to the provision of both inputs and information. The extent of extension services may also be complicated by infrastructure issues: farmers in more accessible, less remote areas may receive more frequent extension visits.

To the extent that farmers do not adopt improved technologies because they are not profitable given the state of the technology and their circumstances, there are two directions that policies can take. The first is to increase productivity of improved varieties and thereby increase output. The second is to reduce input costs for farmers. Subsidizing costs is not sustainable and it is crucial to think about how to reduce input costs by changes in infrastructure, transportation, credit availability, and markets.

It is difficult to determine which factors are behind farmers' decisions not to use new technologies. Farmers often report that input prices are too high, but this means that prices are too high given their knowledge and expected returns. Seeds and fertilizers may be unavailable in a particular region in part because they cannot profitably be sold and used in that area. Inputs may not be available if transportation costs for inputs and outputs are too high. Ethiopia's elevation, terrain, and climate make its agriculture unique, allowing for multi-crop cultivation in small fragmented areas. Moreover, there are vast land and water resources still waiting to be developed. The time may not be too far for Ethiopia to be one of the major producers of maize and other crops in the world.

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Agricultural Input Supply

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Introduction

Agriculture remains by far the most important sector in the Ethiopian economy. Despite its importance, agricultural production and productivity has been low, mainly due to limited use of agricultural inputs such as improved seed and fertilizer. Currently, the use of agricultural inputs is increasing in the country due to the awareness created by the extension system and relatively better supply of inputs. Farmers have shown interest in using various types of improved crop varieties, recommended fertilizers and other inputs. As a result, the demand for improved agricultural inputs especially improved seed has exceeded their supply for the preceding years. The government of Ethiopia devised various systems to tackle the current supply problem in a short period of time.

The government of Ethiopia has developed a five-year Growth and Transformation Plan (GTP). One of the components of this plan is the agricultural sector which is led by the Ministry of Agriculture at the Federal level. Increasing productivity and production of the agricultural sector is the main area of focus throughout the transformation period. To realize this objective, the role of improved agricultural technologies such as improved seeds and fertilizers is indispensable. Moreover, the supply, distribution and marketing of these agricultural inputs at the right place, required amount, relatively low price (competitive price) and the right time are crucial. Therefore, the objectives of this paper are to show past achievements and future plans of agricultural inputs supply and marketing situation at the national level.

Input Supply in the Past Three Years

Fertilizer

The Ethiopian small-scale farmers use low levels of chemical fertilizers and this has contributed to the low crop productivity levels (CSA, 2008). To enhance the use of fertilizers by smallholder farmers the government is working on creating demand through the extension system. The supply and distribution of chemical fertilizers is organized by the Agricultural Input Marketing section of the Ministry of Agriculture. The main activities of the section include:

- Collect total demand for chemical fertilizer from the regions,
- Estimate the needed amount of hard currency for the purchase,
- Facilitate the import (close follow ups on the bid formalities) of fertilizer with the entitled importer.
- Follow up all the deliveries at the port, transportation, distribution and other chain activities until the fertilizer reaches the end-users, i.e., farmers.
- Assure the delivery of the fertilizer as per needed quantity, at affordable prices and most importantly on a timely basis.

Generally, for the last three years, chemical fertilizer supply and usage has been increased dramatically which is mostly attributed to the enhanced demand (due to agricultural extension), affordability and timely supply. The fertilizer usage has increased by 5.4% and 64% in 2009/10 and 2010/11, respectively (Table 1).

Improved seed

Improved seed is the most crucial agricultural input to the sector. To minimize the gap between demands and supplies of improved seed, the government has provided an incentive package in order to attract private seed suppliers. The overall improved seed production and usage has been growing (Table 2). The supply of improved seed has increased by 12.55% and 112.66% in 2009/10 and 2010/11, respectively. This tremendous growth is highly attributed to the scaling-up strategy adopted by the Ministry of Agriculture and the coordinated action by different stakeholders.

Table 1. Total chemical fertilizer purchase, supply and usage in Ethiopia, from 2008/9 to 2010/11.

	Fertilizer (MT)			
Year	Purchased	Supplied	Used	Planned to use
2008/09	442,105	487,574	404,756	700,000
2009/10	626,731	728,202	426,676	756,000
2010/11	530,000	830,000	700,000	820,000
Total	1,598,836	2,045,776	1,531,432	2,276,000

Source: Ministry of Agriculture, Ethiopia

Table 2. Supply of improved seed (hybrid maize and other crops seed) in Ethiopia, from 2008/9 to 2010/11.

	Supply and use of improved seed (t), hybrid maize and other crops			
Year	Hybrid maize	Other crops	Sum	Planned to use
2008/09	8,387.6	16,218	24,605.0	41,542.5
2009/10	9,573.5	18,119	27,692.3	52,778.0
2010/11	16,812.3	42,079	58,891.1	179,835.3
Total	34,773.4	76,416	111,188.4	274,155.8

Source: Ministry of Agriculture, Ehiopia. Note: The regional and crush program production is not included.

Projected Input Demand for the Next Three Years

Fertilizer

In the coming three years, chemical fertilizer demand is expected to grow (Table 3) because of the following reasons:

- The scaling-up strategy will push the chemical fertilizer demand high,
- As fertilizer consumption is highly related to improved seed consumption, an increment in improved seed supply will enhance the fertilizer usage,
- Enhanced irrigation technology usage will also push the fertilizer demand,
- Expected increment of big private commercial farms will raise the fertilizer demand.

Improved seeds

As discussed above, the demand for improved seeds has increased over the years. The Ministry of Agriculture has also estimated that the demand for improved seed will continue to increase due to the following reasons:

- The adopted scaling-up strategy will increase improved seed demand by different users at all levels,
- The undergoing initiatives in improving seed supply through the establishment of regional-based seed enterprises which will engage in the seed production and multiplication programs,
- Promoting seed source (breeder, pre-basic and basic) production and coordinated acts by the Ethiopian Institute of Agricultural Research,
- Use lands of big state farms for seed multiplication program,
- Promoting new and productive varieties and also improving the existing varieties,
- Seed production using irrigation technology,
- High involvement of private seed producers in the seed production program.

Based on data collected from regions on their input requirements and all the aforementioned points, the amount of improved seed demand estimated for the coming three years is presented in Table 4.

Challenges of the Input System

The agricultural input system in the country has been subjected to different problems, particularly in delivering well-synchronized agricultural input production and distribution schemes including:

- Newly released varieties took several years to reach the farmers,
- Most varieties were distributed to the wrong agro-ecologies of the country,
- Reports and data on agricultural inputs were inconsistent,
- Inadequate human capital to follow up the overall agricultural input sector at the federal (national) level,
- Low level of improved animal breeds and agricultural machineries supplied to the farmers.

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Table 3. Estimated fertilizer demand for all crops in Ethiopia, from 2011/12 to 2013/14.

Year	Estimated chemical fertilizer demand (MT)		
	Diammonium phosphate	Urea	Total
2011/12	609,000	345,000	954,000
2012/13	700,000	397,000	1,097,000
2013/14	805,000	456,000	1,261,000
Total	2,114,000	1,198,000	3,312,000

Source: Ministry of Agriculture, Ehiopia.

Table 4. Estimated improved seed demand for all crops in Ethiopia, from 2011/12 to 2013/14.

Year	Estimated demand
2011/12	2,067,000
2012/13	2,375,000
2013/14	2,729,000
Total	7,171,000

Source: Ministry of Agriculture, Ethiopia

SG2000 Maize Technology Transfer Efforts: A Historical Perspective and its Implication to Scaling up Efforts

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The First Generation Problem of Ethiopian Agriculture

Agriculture is the backbone of the Ethiopian economy, contributing 43% of the gross domestic product (GDP), generating about 85% of the foreign currency earning and employing about 83% of the total population. It is also the main source of raw materials for agro-based industries. Despite its importance and the potential of the country for agricultural development, Ethiopian agriculture is characterized as low input-low output subsistence farming that is unable to meet food demand due to low productivity caused by land degradation, fluctuating weather patterns leading to erratic rainfall and recurrent drought. In addition, lack of appropriate and affordable agricultural technologies, inaccessibility to agricultural inputs such as improved seeds, fertilizers and agrochemicals, technically unequipped extension service and other factors have contributed to the low production and productivity of agriculture.

Sasakawa Global 2000 Established in Ethiopia

It was under the above circumstances that Sasakawa Global 2000 (SG2000) started its program in Ethiopia in 1993 with the following objectives:

- Assist the Ethiopian Government in its effort to increase agricultural food production through technology transfer program to small-scale farmers using the existing extension service of the Ministry of Agriculture (MoA).
- Strengthen the capacity of the extension service of the MoA in order to capacitate the extension staff to disseminate proven technologies to farmers.
- Strengthen the linkage between research and extension in order to streamline the process of technology generation, testing and dissemination. To extend improved postharvest and agro processing techniques which are suitable for small-scale farmers.
- Identify socio-economic and other constraints to agricultural development and evaluate alternative ways of alleviating the identified constraints.

SG2000 Approaches

In order to discharge its duties and responsibilities, SG2000 incorporated three major approaches:

- Working in very close collaboration with the extension service of the MoA at all levels, which implemented commercial size farmer managed Extension Management Training Plots (EMTPs) on which improved technologies of food crops were demonstrated.
- Provide classroom and field level training for both extensionists and farmers.
- Identify constraints that limit agricultural development and the proposition of ways to alleviate these constraints. SG2000 has done this through the Office of The Carter Center and Sasakawa Africa Association (SAA) top management staff who quite often visited Ethiopia and had discussions with high level Ethiopian officials.

Field Activities

Demonstration plots were implemented by farmers with technical backstopping through extension. Plot area was usually between 0.25 and 0.5 ha. In 1993, a total of 98 maize EMTPs were implemented in potential maize producing *woredas* of Hawassa, Shashemene, Bako and Sibusire in Oromia and Southern Regional States. By 1995, the number of maize EMTPS increased to 1,795 in four regional states; Oromia, Southern, Amhara and Tigray.

All EMTPs were excellent and average maize yields on EMTPs increased more than threefold (Fig. 1). The plots were visited by farmers, extensionists and Government officials from all over the country. They all appreciated and many were convinced that if science based agricultural technologies are properly implemented by small-scale farmers, it is possible to increase production and productivity provided that public extension service is also made functional.

Government's Decision to Implement National Extension Implementation Program (NEIP)

In 1995 the Government of Ethiopia decided to adopt the SG2000 approach of extension service delivery

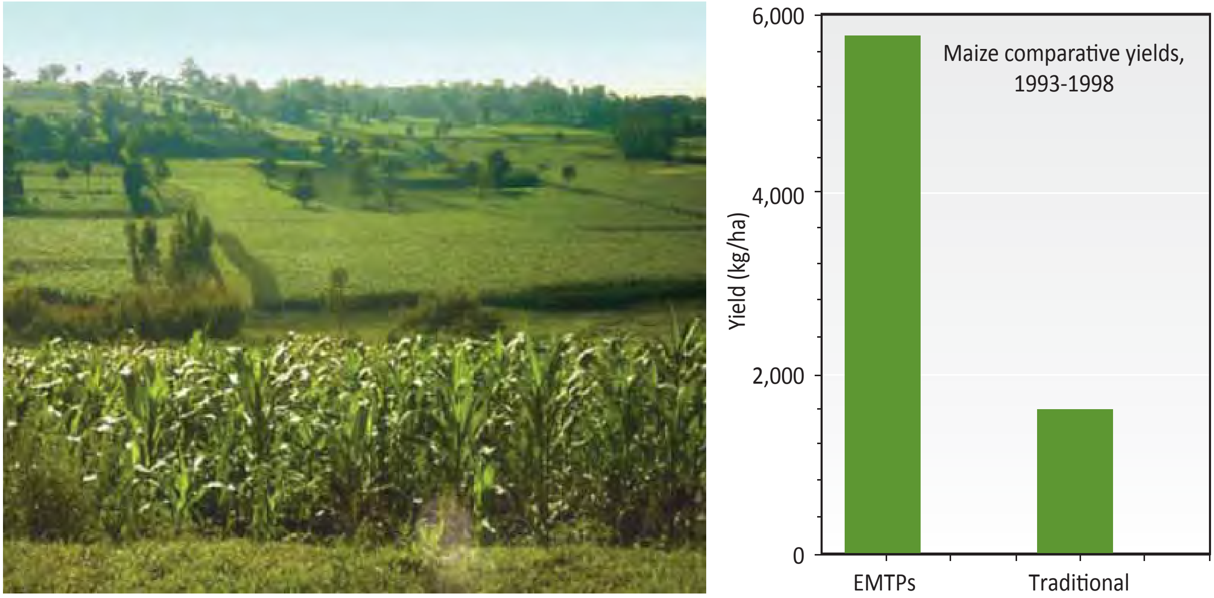

Figure 1. Performance of maize EMTPs and a five-year average yield as compared to traditional plots.

and established over 32,000 half hectare on-farm demonstrations similar to the SG2000 sponsored EMTPs with the purpose of popularizing improved technologies to small-scale farmers. As a result, the average yield per hectare for *tef*, sorghum, wheat and maize demonstrations have gone up to 1.3, 2.7, 2.9 and 4.3 t ha^{-1}, respectively.

In 1996, the government implemented a total of about 350,000 plots all on food crops. The government of Ethiopia was impressed by the outstanding yield performance of NEIP plots and increased to 756,000 plots in 1997. By the year 2001, the number of plots sponsored by government reached over 3,598,130. This increased participation of farmers was beyond the reach of development agents (DAs). Consequently, most of the farmers didn't apply the recommended packages to the improved varieties as recommended by research centers and the yield started to decline (SG2000, 2002).

Bumper Harvest and Second Generation Problem

Owing to generally good weather, increased use of fertilizers and improved seed and because of the introduction of NEIP, grain harvest in 1996 was the highest ever and the country even ventured toward exporting maize. As a result, issues such as grain storage facilities and grain marketing services came to the forefront. In addition, input supply, credit and marketing of bumper harvests remained serious challenges.

Popularization of Post–Harvest Technologies

In the 1995/96 crop season SG2000 initiated a vigorous campaign of introducing improved grain storage facilities at the homestead level (Fig. 2). Several extension workers and farmers were trained in construction methods of improved grain silos using locally available materials. In addition, SG2000 sponsored manufacturing of and popularization of hand operated maize shellers.

Figure 2. Improved grain silo sponsored by SG2000.

In Ethiopia crops are traditionally threshed by treading by animals or beating with clubs. The process is very time consuming and backward. In view of increased production and productivity the need for changing this archaic threshing system was eminent. As a result, SG2000 introduced prototypes of a multi-crop thresher (Fig. 3) and sponsored manufacturing and popularization activities.

Maize and Conservation Tillage

In 1998, SG2000, in collaboration with Monsanto and Makobu Enterprise, started popularizing conservation tillage technologies. The outcome of this demonstration indicated that there was a significant human labor and oxen labor saving recorded as a huge benefit to farmers. These benefits were over and above the natural resource saving (Fig. 4). In the meantime, SG2000 worked with Bako Maize Research Center to facilitate the introduction of quality protein maize (QPM) to Ethiopia. The result of aggressive testing of QPM experimental varieties under 22 environments indicated that the experimental hybrid CML144/CML159//CML176 was found to be promising.

Yield Increase and the Third Generation Problem

As indicated above, yield level in the government sponsored plots started declining as a result of mono-cropping, application of low levels of fertilizer and under employment of other management practices. As a result of declining trends of yield, DAs and farmers were complaining that maize was not as good and hence asked for the introduction of new varieties.

Establishment of Standard Extension Management Training Plots (Semtp) 2002–2003

Considering the seriousness of this allegation for technology adoption, SG2000 established SEMTPS in major food crop growing areas of Oromia and Southern regional states and tested maize, wheat and *tef* under

Figure 3. Demonstration of maize shelling using multi-crop thresher.

Figure 4. Quality Protein Maize grown under conservation tillage.

proper supervision of SG2000. Several field days were organized for farmers, extension workers and Government officials.

The result of SEMTPs indicated that crop stand and final crop yield was found to be impressive and as high as the previous seasons' yields under SG2000 supervision, and hence, crop varieties used did not show any deterioration or contamination.

The reduced grain yield was because of one or more of the following:

- Seed of crop varieties used by farmers were not of quality, as seen from the uniformity of the crops in the field.
- The recommended packages were not used properly.
- There was no adequate follow up by DAs because they were overwhelmed by the expanded number of demonstration plots. As a result farmers did not apply the recommended packages.

Therefore, once packages of technologies are made available to farmers, close supervision has to be made by DAs for proper application of the package. Improved varieties alone can't bring about expected yield changes unless followed by proper crop management practices. In addition, the farmers should obtain quality seed of a certain variety at the right time and place.

Implication of SEMTP Findings to the Government of Ethiopia's Effort of Doubling Crop Yield by the End of the 5 Year Growth and Transformation Plan Period (2015)

Some of the fertile grounds for doubling crop production include:

- Government commitment to agricultural development is intact as indicated by formulation of different policies to create enabling environments for agricultural development.
- To alleviate problem of implementation capacity, the government has established 25 Agricultural technical and vocational education trainings (ATVETs) and trained close to 70,000 DAs.
- Commitment to establish 18,000 Farmer Training Centers (FTC) to improve extension service delivery.
- Decentralized decision making process by empowering *woredas* or districts.

Ways Forward for Challenging Issues on the Ground

Assessment of the extension service delivery system by the International Food Policy Research Institute (IFPRI) team (Davis, 2009), while appreciating government's commitment to agricultural development in its entirety, pointed out that:

- Farmers participatory decision making capacity has to be strengthened.
- Diversify the spectrum of extension service delivery.
- Strengthen the extension system in terms of resourcing at *woreda* and FTC level.
- DA capacity should be strengthened to address diverse needs of farmers.
- Lack of mobility by DAs and subject matter specialists (SMSs) to provide extension service delivery should be improved.
- Performance based incentive system, including carrier path development needs to be put in place.
- Strengthen linkages at all levels, within the extension system, between extension and all development partners.

Pilot Project to Address the Issues

A tripartite pilot project including the MoA, OXFAM America and Sasakawa Africa Association/SG2000 supported by Bill and Melinda Gates Foundation is initiated on September, 2010 to improve extension service delivery by addressing the aforementioned gaps in the extension system

Concluding Remarks

Sustainable increase of production and productivity can only be achieved through utilization of science based agricultural technologies. Dissemination and large scale utilization of science based technologies require, among other things, harmonized partnership with shared responsibilities. Moreover, creating an enabling environment such as a good input delivery system, marketing, farmers' access to credits, etc is essential to achieve perceived development objectives.

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Maize Seed Production in Research Centers and Higher Learning Institutes of Ethiopia

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Introduction

In sub-Saharan Africa countries continue to suffer from food deficits and poverty, despite large areas of arable land, abundant water for irrigation and availability of productive labor. Nearly 70% of the population live in rural areas and are engaged in agriculture. Therefore, major efforts to alleviate poverty and achieve food security must focus on the agricultural sector (CTA, 1999).

Ethiopia is the third most populated country in sub-Saharan Africa, with a population close to 74 million. Agriculture is the base of Ethiopia's national economy. Thus, to feed the ever increasing population of the country, seed is a fundamental input to enhance agricultural productivity. Indeed, ensuring food security needs seed security which includes activities undertaken to secure access to adequate quantities of good quality seeds of improved and adapted crop varieties at all times by farming households.

Agricultural research centers and universities are producing basic and certified maize seeds and distributing them to the users, even though such commitment is not necessarily part of their formal mandates. The responsibilities of these institutes are to develop improved varieties, produce breeder and pre-basic seeds and supply these seeds to the basic seed producers (Hadji *et al.*, 2002).

As it had been before the current decade (Gugsa and Sahlu, 1993; Hadji *et al.*, 2002), research centers mandated for maize research continued to multiply and distribute improved maize seed in their respective agro-ecologies in the last decade in Ethiopia. The objective of this paper is, therefore, to summarize the production and distribution of maize seed by research centers and universities in the country in the 2000s and to give highlights of agronomic recommendations for hybrid maize seed production.

Maize Seed Production

Maize seed production at Bako Agricultural Research Center

Bako Agricultural Research Center played the leading role in the production of suitable maize hybrids and open-pollinated varieties (OPVs), and distribution of maize seeds to the subsequent users in the country (Hadji *et al.*, 2002). Currently, this includes seeds/parental seeds of five OPVs (Abobako, GuttoLMS$_5$, Kuleni, Gibe1, and Gambella composite) and seven hybrids (BH140, BH540, BH543, BH660, BH670, BHQP542, and BHQPY545). All classes of seeds, *viz*. breeder, pre-basic, basic and certified, of these varieties have been produced at Bako Agricultural Research Center since the release of the varieties.

Breeder/pre-basic seed production at Bako National Maize Research Project

During the last decade, basic seed producers used to submit their demands of breeder/pre-basic seed in advance to the Bako National Maize Research Project. Depending on the quantity demanded, the Bako National Maize Research Project produced seeds of parental lines of the released maize hybrids and OPVs in isolation fields in the main- and off-seasons and supplied them to the Bako Agricultural Research Center and other users throughout the country for subsequent pre-basic and basic seed production (Table1). Experiences at Bako showed that some parental lines like 1421e, and 1447b were not performing well in the off-season (in the dry season using irrigation) and consequently, decided to carry out the seed production of these inbred lines only during the main-season (major rainy season). Conversely, CML161 (the female parent of BHQPY545) performed well in the off-season.

NB: only 0.1–0.2 t of the parental lines OPVs were maintained as breeder seed and the rest were distributed as breeder/pre-basic seed. In addition, F_1 seeds of BHQP542, BH670, BH543 and BHQPY545 were produced in isolation fields for demonstration for at least 2–3 years immediately after release (data not shown).

Basic and certified seed production at Bako Agricultural Research Center

The commencement of basic seed production in research centers in Ethiopia dates back to the early 1980s, with the production of OPVs at Jimma Agricultural Research Center. Bako Agricultural Research Center (under Oromia Agricultural Research Institute) had been the leading center in producing maize basic seeds in the country. Hadji *et al.* (2002) reported that basic seed production of hybrids at Bako Agricultural Research Center began in the early 1990s. Over the last decade, large quantities of basic seeds of hybrids and OPVs were produced and distributed to private and public certified seed producers in the country by the Bako Agricultural Research Center (Table 2).

In the 1980s, certified seed was almost entirely produced by State Farms. Small quantities were produced by the Bako Agricultural Research Center. Bako Agricultural Research Center produced and distributed certified seeds of the varieties released by the National Maize Research Project to farmers in the country during the 1990s (Hadji *et al*., 2002). In the 2000s, the center continued to produce and distribute

Table 1. The quantities (t) of breeder/pre-basic seed produced during main- and off-seasons by the Bako National Maize Research Project (Ethiopian Institute of Agricultural Research), 2001–2010.

	2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		
Varieties	Main	Off	Main	Off	Main	Off	Main	Off	Main	Off	Main	Off	Main	Off	Main	Off	Main	Off	Main	Off	Total
A7033	2.6	–	0.7	–	1.6	–	0.8	–	–	–	1.0	–	0.8	–	2.7	–	3.6	–	3.8		17.6
F7215	0.8	–	0.5	–	1.4	–	1.2	–	1.2	–	0.7	–	0.7	–	0.8	–	1.9	–	1.6		10.8
1421e	–	–	1.2	–	0.4	–	–	–	–	–	–	–		–	0.5	–	–	–	2.1		4.2
1447b	0.2	–	–	–	2.2		0.7	–	–	–	1.0	–	1.2	–	1.7	–	1.0	–	0.5		8.5
SC22	5.0	1.0	0.6	–	–	0.8	–	–	–	1.6	–	–		2.0	–	–	0.5	–	–	0.6	12.1
124b(113)	–	–	0.5	–	–	–	–			0.1	–	–	0.4	0.4	–		–	–	0.5		1.9
124b(109)	–	–	–	–	–	–	–	0.5	0.1	3.0	–	1.0		0.5	–	0.2	–	0.2	–	0.6	6.1
CML197	–	0.5	–	–	0.5	0.1	–	0.1	0.7	–	0.7	–	3.3	–	3.2	–	2.4	–	3.2		14.7
CML144	–	–	0.4	–	–	–	–	–	0.5	–	2.1	–		–		–	–	0.4	–	0.4	3.8
CML159	–	–	0.3	–	–	0.1	–	–	0.2	–	0.3	–	0.1	–	0.2	–	0.3	–	–		1.5
CML176	–	–	–	0.4	0.2	–	0.5	–	0.2	–	2.3	–	2.4	–	0.8	–	0.7	–	0.4		7.9
GuttoLMS$_5$	0.1	–	–	0.5	–	0.2	–	–	–	0.1		–		–	–	0.4	–	–	–	0.4	1.7
Gibe1	3.1	–	–	0.6	–	1.4	–	0.6	–	–	–	1.5		1.4		1.5	–	0.8	–		10.9
Kuleni	–	–	–	–	–	0.5	0.2	0.6	–	–	–	0.7		–	0.3		–	0.1	–	0.4	2.8
Abo Bako	–	–	–	0.3	–	0.3	–	–	–	–	–			–	–	0.3	–	0.3	–		1.2
Gambella Composite	–	–	–	0.6	–	1.5	–	–	–	0.3	–	–	–	1.0	–	0.7	–	1.1	–		5.2
Obatampa	5.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		5.8
CML161	–	–	–	–	–	–	–	–	–	–	–	–	–	0.2		0.7		0.6	–	0.7	2.2
CML165	–	–	–	–	–	–	–	–	–	–	–	–	–	0.1	0.5	–	–	–	0.4		1.0
AMSRC	–	–	–	–	–	–	0.4	–	–	–	–	–	–	–	–	–	–	–	–		0.4
NMCM41 1881(32)	8.6	–	–	–	–	–	–	–	1.4	–	–	–	–	–	–	–	–	–	–		10.0
Total	26.2	1.5	4.2	2.4	6.3	4.9	3.8	1.8	4.3	5.1	8.1	3.2	8.9	5.6	10.7	3.8	10.4	3.5	12.5	3.1	130.3

Source: Bako National Maize Research Program (unpublished data).
NB: only 0.1–0.2 t of the parental lines and open-pollinated varieties (OPVs) were maintained as breeder seed and the rest were distributed as breeder/pre-basic seed. In addition, F_1 seeds of BHQP542, BH670, BH543 and BHQPY545 were produced in isolation fields for demonstration for at least 2–3 years immediately after release (data not shown).

Table 2. Amount of basic seed produced during the main- and off-season at Bako Agricultural Research Center, 2001–2010.

	Production (t)										
Parents	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Gutto LMS$_5$	23.9	14.7	–	13.2	43.4	–	15.4	–	24.5		135.1
SC22	13.5	26.7	–	8.0	23.1	11.0	50.7	50.1	67.5	34.0	284.6
A7033/F7215	27.1	57.1	13.9	7.7	35.6	14.2	16.8	47.0	77.7	48.0	345.1
1421e	12.0	18.1	9.9	2.6	1.6	13.8	8.9	22.7	13.0	57.2	159.8
124b(113)	6.1	5.7	8.6	7.4	1.5	14.1	16.6	10.7	–	11.6	82.3
CML144/CML159	–	0.7	1.2	0.4	–	5.6	–	1.7	3.8	2.2	15.6
NSCM41 1881(32)	–	–	8.0	–	–	–	–	–	–	–	8.0
SC22/124–b(109)	–	–	–	–	–	–	8.2	9.4	6.0	3.4	27.0
Total	82.6	123.0	41.6	39.3	105.2	58.7	116.6	141.6	192.6	156.4	1,057.5

Source: Bako Agricultural Research Center, farm management team (unpublished data).

certified seeds of hybrids and OPVs released by the project up to the late 2000s (Table 3). Since 2007, the center has ceased the production of certified seed, except in 2010, and continued with the production of basic seed to satisfy the ever increasing demand of basic seed in the country by public and private certified seed producers.

Maize seed production in other research centers

Highland maize research was initiated in 1997 at Ambo Agricultural Research Center in a joint effort by CIMMYT and East and Central African maize programs to serve as a regional nursery for eastern and central Africa, and to introduce, develop and improve highland maize technologies in Ethiopia. In addition to the breeding activities, Ambo Agricultural Research Center produced breeder, pre-basic, basic, and certified seeds of released maize varieties in collaboration with Kulumsa Agricultural Research Center for the highland sub-humid agro-ecology of the country (Tables 4, 5, and 6). Furthermore, in the past five years, seed production of OPVs (Hora and Kuleni) was also carried out at the Holetta Agricultural Research Center to address seed demands of farmers and other stakeholders in the vicinity of Holetta (Table 7).

Table 5. The amount of pre-basic/basic seed production at the Ambo and Kulumsa Agricultural Research Centers during the main- and off-seasons, 2005–2009.

	Production (t) across year and season						
	2005		2006		2007	2008	2009
Parent/variety	Main	Off	Main	Off	Main	Main	Total
Kuleni	0.7	–	–	–	4.3	11.9	16.9
Hora	4.0	0.9	–	–	1.9	26.6	33.4
FS48	–	–	1.1		1.0	7.7	9.8
Kit21/Kit32	–	–	–	0.1	0.1	–	0.2
Kit21	–	–	–	–	–	1.3	1.3
Kit32	–	–	–	–	0.1	7.7	7.8
FS89	–	–	–	–	0.3	6.2	6.5
FS59	–	–	–	–	–	0.7	0.7
FS67	–	–	–	–	–	0.2	0.2
S59/FS67	–	–	–	–	0.1	6.9	7.0
Total	4.7	0.9	1.1	0.1	7.8	69.2	83.8

Source: Ambo Agricultural Research Center (unpublished data).

Table 3. Amount of certified seed produced at the Bako Agricultural Research Center, 2001–2010.

	Production (t)										
Varieties	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
BH140	15.0	–	–	–	–	–	–	–45	–		15.0
BH660	85.4	143.3	–	–	129.3	86.6	94.1	0.2	–	13.2	552.1
BH540	3.5	–	–	–	83.0	50.1	–	–	–		136.6
BHQP542	–	0.7	–	1.4	–	–	–	–	–		2.1
Kuleni	2.5	–	–	–	17.1	–	–	–	–		19.6
Gambela Composite	–	–	–	–	40.5	41.4	–	–	–		81.9
Total	106.4	144.0	0.0	1.4	270.0	178.1	94.1	0.2	0.0	13.2	807.3

Source: Bako Agricultural Research Center, Farm Management team (unpublished data).

Table 4. The amount of breeder seed produced at the Ambo Agricultural Research Center, 2004–2009.

	Production (t) across year and season								
	2004	2005	2006		2007		2008	2009	Total
Parent/variety	Main	Main	Main	Off	Main	Off	Main	Main	
Hora	0.3	–	–	–	0.2	–	–	0.4	0.9
FS48	0.3	0.3	–	0.6	0.1	–	–	–	1.3
Kuleni	–	–	–	–	0.5	–	–	0.2	0.7
Kit21	–	–	–	–	–	0.1	–	–	0.1
Kit32	–	–	–	–	–	0.1	–	0.2	0.3
FS89	–	–	–	–	–	0.1	–	–	0.1
FS59	–	–	–	–	–	–	0.1	–	0.1
FS67	–	–	–	–	–	–	0.1	–	0.1
Kit23	–	–	–	–	–	–	0.2	–	0.2
Total	0.6	0.3		0.6	0.8	0.3	0.4	0.8	3.8

Source: Ambo Agricultural Research Center (unpublished data)..

The Melkasa Agricultural Research Center maintained and increased seeds of low moisture stress tolerant maize varieties. Eight low moisture stress tolerant/ escape OPVs (Katumani, Melkasa1, Melkasa2, Melkasa3, Melkasa4, Melkasa5, Melkasa6Q and Melkasa7) were maintained by the center. Hence, the center produced and distributed the breeder/pre-basic and basic seeds of these varieties and supplied to basic and certified seed producers, respectively, in the past decade (Tables 8 and 9). In addition to this, 45 t of certified seed of Melkasa2 was produced in 2007 and 2009 on farmers' fields for scaling-up production. The Werer Agricultural Research Center was also involved in the production of maize seed for the low moisture stress areas. As a result, the center increased 6.4 t of Melkasa2 and 7.1 t of GuttoLMS5 in 2006 and 2008 off-seasons, respectively, under irrigation and distributed them to the farmers in the Afar region.

A significant amount of certified seeds of maize varieties released for the mid-altitude sub-humid agro-ecology of Ethiopia (BH530, BH540, BH541, BHQP542, BH543, and Gibe1) were multiplied at Pawe Agricultural Research Center and distributed to the farmers in the Benishangul-Gumuz region during the last decade (Table 10). The center also produced basic seeds of some varieties (Table 11).

Since the 2008 cropping season, the Adet Agricultural Research Center has also produced pre-basic/basic seeds of maize varieties adapted to a mid-altitude sub-humid agro-ecology (Table 12). Furthermore,

Table 6.The amount of certified seed produced and distributed (t) to the farmers by the Ambo Agricultural Research Center, 2005–2009.

Varieties	2005	2006	2007	2008	2009	Total
Arganne (AMH800)	3.0	3.0	4.0	1.3	–	11.3
Wenchi	–	–	–	0.4	–	0.4
Total	3.0	3.0	4.0	1.7	–	11.7

Source: Ambo Agricultural Research Center (unpublished data).

Table 7. The amount of certified seed produced and distributed (t) to farmers and other stakeholders by the Holetta Research Center, 2005–2009.

Variety	2005	2006	2007	2008	2009	Total
Kuleni	0.3	–	–	–	–	0.3
Hora	0.4	0.7	1.5	2.3	0.4	5.3
Total	0.7	0.7	1.5	2.3	0.4	5.6

Source: Holetta Agricultural Research Center (unpublished data).

Table 8. The amount of breeder/pre-basic seed of different maize varieties produced (t) at the Melkasa Agricultural Research Center, 2001-2009.

Variety	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total
Melkasa1	0.2	0.2	2.5	0.2	0.2	–	–	0.3	–	3.5
Melkasa2	–	–	–	0.2	0.4	0.4	0.3	0.3	3.4	5.0
Melkasa3	–	–	–	0.3	0.2	0.2	0.4	–	–	1.1
Melkasa4	–	–	–	–	0.3	0.3	0.2	0.3	–	1.1
Melkasa5	–	–	–	–	–	0.3	0.3	0.2	0.3	1.1
Melkasa6Q	–	–	–	–	–	0.3	0.2	0.3	0.3	1.1
Melkasa7	–	–	–	–	–	0.3	0.2	–	–	0.5
Total	0.2	0.2	2.5	0.5	1.1	1.8	1.6	1.4	4.0	13.4

Source: Melkasa Agricultural Research Center, Maize Research team (unpublished data).

Table 9. The amount of basic seed of different maize varieties produced (t) at Melkasa Agricultural Research Center, 2001– 2009.

Variety	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total
Katumani	126.0	115.1	10.7	93.6	31.7	–	–	–	–	–	377.1
Melkasa1	2.9	4.3	10.9	26.1	69.2	120.7	50.1	65.5	29.2	–	378.9
Melkasa2	–	–	–	–	–	3.7	19.8	20.3	8.2	–	52.0
Melkasa3	–	–	–	–	–	2.6	110.3	–	–	–	2.9
Melkasa4	–	–	–	–	–	–	–	12.4	13.6	–	26.0
Melkasa6Q	–	–	–	–	–	–	–	–	5.5	9.8	15.3
Melkasa–7	–	–	–	–	–	–	–	–	7.3	–	7.3
Total	128.9	119.4	21.6	119.7	100.9	127.0	70.2	98.2	61.8	9.8	859.5

Source: Melkasa Agricultural Research Center, maize research team (unpublished data).

the Jimma Agricultural Research Center has long been maintaining and multiplying the basic seeds of Ukiriguru composite B (UCB) (Hadji *et al.*, 2002). In the same way, the center has continued to produce the breeder and basic seeds of UCB and Morka (improved UCB) over the last decade (Tables 13 and 14).

To meet the increasing demand of basic and certified seeds in the southern region, research centers (regional and federal) operating in the region were involved in the multiplication of pre-basic and basic seed of released varieties. In this regard, the Hawassa Agricultural Research Center with full technical support from the Hawassa National Maize Research Center multiplied the pre-basic and basic seeds of parents of some maize hybrids (BH540, BH660, and BH543) in the region (Table 15). This contributed to the availability of certified seed in the region.

Maize seed production by higher learning institutes

Besides training medium to high level professionals, Haramaya and Hawassa Universities were involved in early generation maize seed production and distribution. Haramaya University produced a significant amount of seeds of Katumani, Melkasa1 and Gibe1 and distributed them to the farmers in the eastern part of the country during the past decade (Table 16). Similarly, Hawassa University produced seeds of different OPVs (Table 17) and distributed them to different stakeholders (farmers, Food and Agriculture Organization, GTZ and other non-government organizations).

Recommended Practices for Hybrid Maize Seed Production

The agronomic management practices recommended for grain production are also important in seed production. However, successful seed production requires a much higher level of management skill and is far more labor and time consuming than grain

Table 11. The amount of basic seed (t) of different maize varieties produced (in quintals) during 2001–2009 at the Pawe Research Center.

Variety	2001	2003	2008	2009	Total
Pop43	3.0	1.5	–	–	4.5
101e	–	2.3	–	–	2.3
SC22	–	–	0.9	0.1	1.0
124b(113)	–	–	0.1	0.2	0.2
CML197	–	–	–	0.2	0.2
SC22/124b(113)	–	–	–	0.5	0.5
Total	3.0	3.8	1.0	1.0	8.7

Source: Pawe Agricultural Research Center (unpublished data).

Table 12. Pre-basic/basic seed production (t) at the Adet Agricultural Research Center during 2008.

Varieties	Pre basic	Basic	Total
SC22	–	1.6	1.6
124b(113)	–	1.8	1.8
A7033	1.8	–	1.8
F7215	1.5	–	1.5

Source: Adet Agricultural Research Center (unpublished data).

Table 13. Breeder seed multiplication of Morka and Ukiriguru composite B (UCB) at the Jimma Agricultural Research Center, 2001–2009.

	Morka		UCB		
Year	Area (ha)	Quantity (t)	Area (ha)	Quantity (t)	Total Quantity (t)
2001	–	–	0.05	0.1	0.1
2002	–	–	0.05	0.1	0.1
2003	–	–	0.05	0.1	0.1
2004	0.1	0.3	0.05	0.1	0.4
2005	0.1	0.3	0.05	0.1	0.4
2006	0.1	0.3	0.05	0.1	0.4
2007	1.0	1.8	0.05	0.1	1.9
2008	0.5	1.5	0.05	0.1	1.6
2009	0.6	1.5	0.05	0.1	1.6
Total	2.4	5.7	0.5	0.9	6.6

Source: Jimma Agricultural Research Center (unpublished data).

Table 10. The amount of certified seed of different maize varieties produced (in tons) at the Pawe Agricultural Research Center, 2001–2009.

Variety	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total
BH530	8.8	6.6	9.4	3.8	–	–	–	–	–	28.5
BH540	–	–	–	–	7.1	4.6	10.9	11.6	12.6	46.7
BH140	–	–	–	–	1.5	2.4	–	–	–	3.9
BHQP542	–	–	3.0	7.9	4.0	–	–	–	–	14.9
BH541	–	–	–	–	–	0.4	1.5	–	–	1.9
Gibe1	0.2	2.4	–	9.6	7.8	4.6	–	6.5	6.0	37.1
BH543	–	–	–	–	–	–	1.8	6.9	–	8.7
Total	8.9	9.0	12.4	21.3	20.4	12.0	14.2	25.0	18.6	141.7

Source: Pawe Agricultural Research Center (unpublished data).

production (Ireland *et al.,* 2006). The detailed guidelines for maize seed production and processing in Ethiopia have been presented in a maize breeding and hybrid seed production manual (NMRP, 2010). In this particular section some highlights of the practices specific to hybrid maize seed production will be discussed.

Table 14. Basic seed production of Morka and composite B (UCB) at the Jimma Agricultural Research Center from 2001–2009.

	Morka		UCB		
Year	Area (ha)	Quantity (t)	Area (ha)	Quantity (t)	Total Quantity (t)
2001	–	–	10.0	32.4	32.4
2007	0.5	2.0	–	–	2.0
2008	1.5	6.8	–	–	6.8
2009	9.0	3.5	–	–	3.5
Total	11.0	12.3	10.0	32.4	44.7

Source: Jimma Agricultural Research Center, (unpublished data).

Table 15. Pre-basic and basic seeds produced by the Hawassa Agricultural Research Center, 2008–2009.

Year	Parent	Amount produced (t)	Multiplication site
2008	124b(113)	2.9	Arba Minch
	SC22	2.9	Arba Minch
	A7033	2.9	Arba Minch
	F7215	2.5	Arba Minch
	1421e	0.1	Arba Minch
2009	A7033/F7215	7.2	Arba Minch
	1421e	1.5	Arba Minch
	SC22	1.8	Arba Minch
Total		21.8	

Source: Hawassa Agricultural Research Center (unpublished data).

Isolation distances

The maize seed production field should be separated from other fields of maize by at least a minimum distance, and it is essential to prevent pollination from unwanted pollen and to avoid mechanical mixture (NMRP, 2010). The isolation distance varies depending on the type of variety and the availability of physical barriers (Hadji *et al*., 2002). The minimum isolation distance may also be considerably reduced by planting border rows of the pollinator parent (the male parent) and by choosing a larger field for maize seed production (Ireland *et al.,* 2006). Therefore, the minimum isolation distance used has been absolute for the production of breeder seed; set at 400 and 300 m for basic and certified seeds, respectively.

Table 17. Open-pollinated varieties multiplied and distributed by Hawassa University, 2004–2009.

Year	Variety	Amount produced (t)	Multiplication site
2004	A511	1.0	Hawassa
2005	ACV6	10.1	Hawassa
	ACV3	4.7	Hawassa
2006	A511	1.5	Hawassa
	ACV6	2.6	Ziway
	Gibe1	1.7	Hawassa
2007	Melkasa1	0.8	Ziway
2008	Melkasa1	2.2	Ziway
2009	Gibe1	24.0	Butajira
	Gibe1	13.0	Umbulo Wachu
	Melkasa1	2.3	Ziway
Total		63.9	

Source: Hawassa University

Table 16. The amount of seed produced at Haramaya University and distributed to farmers in the area, 2001–2009.

	Katumani		Melkasa1		Gibe1	
Year	Area (ha)	Amount produced (t)	Area (ha)	Amount produced (t)	Area (ha)	Amount produced (t)
2001	–	7.9	–	–	–	–
2002	14	54.5	–	–	–	–
2003	–	60.7	–	–	–	–
2004	30	82.0	–	–	–	–
2005	20	31.5	–	–	–	–
2006	19	18.0	–	–	–	–
2007	18	41.0	–	–	–	–
2008	20	38.4	–	–	–	–
2009	25	71.0	3.5	5.0	–	–
2010	34	39.0	3.0	6.0	0.8	2.2
Total	180	444.0	6.5	11.0	0.8	2.2

Source: Haramaya University (unpublished data).

Female to male ratio

Designated male and female parents should be planted in the correct row ratio for effective hybrid seed production in maize. The parents' characteristics determine the planting pattern used. The most common female to male ratios used in hybrid maize seed production are 4:1, 2:1, 3:1 and 6:2. In Ethiopia, 6:2 and 3:1 female to male ratios were most commonly used for hybrid seed production. For the hybrids released for the highland sub-humid agro-ecology (Arganne, Wenchi and Jibat) a 3:1 female to male ratio was used at the Ambo Agricultural Research Center.

Staggering

Good seed set in seed parent can be achieved by chronological adjustment of pollen shedding and silking (nicking), and by prolonging the effective flowering period, planting design, planting ratio and staggered planting. Among the hybrids released by the national maize research: BH660, BH670, BH543 and BH540 required staggered planting of male and female parents so as to synchronize the silking of the female parent with the pollen shed of the male parent for effective pollination. On the other hand, BHQP542, BHQPY545, BH140, Arganne, Jibat and Wenchi did not need staggered planting, i.e., the female and male parents were planted on the same day for the production of the hybrids. (Table 18).

Rouging

Rouging is the removal of plants having characteristics different from the desired variety—which are off-types, that is, phenotypically different from the plants of the variety under production. It is an important aspect of

Table 18. Recommendations for planting basic and certified seeds of the released hybrids by the National Maize Research Program.

Variety	Pedigree	Type of seed	Female parent	Male parent	Planting recommendations
BH660	A7033/F7215//1421e	Certified seed	A7033/F7215	1421e	The male parent (1421e) should be planted 10 days before planting the female parent (A7033/F7215)
BH670	A7033/F7215//1447b	Certified seed	A7033/F7215	1447b	The male parent (1447b) should be planted 10 days before planting the female parent (A7033/F7215)
BH660 and BH670	A7033/F7215	Basic seed	A7033	F7215	The male and female parents should be planted on the same day
BH543	SC22/124b(109)//CML197	Certified seed	SC22/124b(109)	CML197	The male parent (CML197) should be planted five days before planting the female parent (SC22/124b (109)), i.e., plant the female parent on the fifth day after planting the male parent
	SC22/124b(109)	Basic seed	SC22	124b(109)	The male and female parents should be planted on the same day
BHQP542	CML144/CML159// CML176	Certified seed	CML144/CML159	CML176	The male and female parents should be planted on the same day
	CML144/CML159	Basic seed	CML144	CML159	The male and female parents should be planted on the same day
BHQPY545	CML161/CML165	Certified seed	CML161	CML165	The male and female parents should be planted on the same day
BH540	SC22/124b(113)	Certified seed	SC22	124b (113)	The female parent (SC22) should be planted seven days before planting the male parent (124b(113))
BH140	GuttoLMS5/SC22	Certified seed	GuttoLMS5	SC22	The male and female parents should be planted on the same day
Argane	Kuleni/FS48	Certified seed	Kuleni	FS48	The male and female parents should be planted on the same day
Wenchi	Kit21/Kit32//FS89	Certified seed	Kit21/Kit32	FS89	The male and female parents should be planted on the same day
	Kit21/Kit32	Basic seed	Kit21	Kit32	The male and female parents should be planted on the same day
Jibat	FS59/FS69//Kit2	Certified seed	FS59/FS69	Kit2	The male and female parents should be planted on the same day
	FS59/FS69	Basic seed	FS59	FS69	The male and female parents should be planted on the same day

seed production and is necessary to prevent out-crossing and mechanical mixture. The off-type plants and diseased plants have to be regularly removed from the field either by uprooting or by cutting at the ground level throughout the growing stage of the crop. The off-type plants may differ in plant height, leaf characters, stalk color, silk and tassel color, flowering time, and maturity. During the vegetative stage rouging is done based on height of the plant, color of leaf, and leaf orientation; and during flowering stage rouging is done based on flowering time (early or late flowering), color of tassel and silk.

Detasselling

In hybrid seed production, the tassels from the female parent must be removed so that only pollen from the male parent is present in the seed field for cross-pollination. The timing of detasselling is critical; if done too early, it can damage the plant and if done too late there is a risk of self-pollination. The method in principle is simple as it involves the manual removal of the pollen-producing organ, the tassels, of the female parent. However, it is labor intensive and requires a team of skillful professionals and many dedicated technicians and/or workers with good eyesight, gentle hands, a lot of patience and commitment. At Bako, the maize seed production fields were handled by a crew of experienced workers to ensure that the field was clear of female tassels. This required several passes by the crew (each row was detasselled by one worker and all female tassels were removed). After the silks of the female parent were pollinated, the male rows were removed to avoid possible contamination of the hybrid seed.

Conclusion

To meet the country's food security needs, it is important to make available quality seeds, in adequate quantities on a timely basis to Ethiopian farmers. Research centers played a major role in the production of all classes of seeds to transfer the improved varieties to the farmers. With the increased demand for basic seed in the country, they concentrated on the production and distribution of breeder/pre-basic and basic seeds in the 2000s. However, with the given capacity, the research centers could not satisfy all the demands of basic seed in the country. Therefore, seed producers, both public and private, should produce their own pre-basic and basic seed, as has already been initiated by some seed producers. On the other hand, research centers should build their capacity and concentrate on new technology generation, and maintenance, production and distribution of quality breeder/pre-basic seed in the future.

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Maize Seed Production and Distribution to the Public Sector in Ethiopia: The Case of Ethiopian Seed Enterprise

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Introduction

Maize is among the most important food crops for mankind. Besides its promises to be the source of food for multitudes, it also stands first in attracting commercial seed business. Commercial seed companies enjoy excessive profits from hybrid maize seed business every year. In Ethiopia, several private and public seed companies are operating exclusively in the production and sales of maize seed from hybrids developed by the Ethiopian Institute of Agricultural Research (EIAR). Referring to the formal seed supply status of the country, maize ranks second in seed sales for the Ethiopian Seed Enterprise (ESE); 22.4% in the last five years (2006–2010), surpassed only by wheat.

Currently, all the operational seed companies are engaged in maize seed production and supply. Except the multinationals, all seed producers obtain breeder seeds of the locally developed varieties from the public research system. The ESE and all the major maize producing regions, through their regional agricultural research institutes (RARIs), began increasing the parental seed of the popular hybrids in 2008. Nevertheless, this move could not solve the shortage of parental seed especially in the local private seed sector. Hence, the private seed producers have been allowed to increase the production of parental seeds. Through this liberalization, helped through the availability of the parental seeds leading to the growth of the hybrid seed supply, quality remained the main concern due to the poor quality control institutional set up. The main intention of this paper is to review the progress and the outstanding challenges faced by the maize seed production and distribution undertaken by the ESE since 2001.

Breeder Seed Supply and Parental Seed Multiplication

Research centers produced and supplied the parental and basic seed of the hybrids and open-pollinated varieties (OPVs) exclusively to the ESE for certified seed production for several years. ESE used to be the sole hybrid maize producer in the public sector. The recent developments in the emergence and operation of various local private seed companies and regional seed enterprises brought about some changes in the basic and parental seed supply system. The local private and regional seed enterprises have obtained access to the hybrids and OPVs released by the public research system. Hence these seed companies share the parental seed produced each season.

The demand for parent seed increased rapidly and research centers alone could not satisfy the need of all seed producers. The shortfall was further aggravated when the number of released hybrids increased. Ultimately, the lower productivity of the lines coupled with a growing demand amplified the magnitude of the gap between the demand and the supply. It was apparently impossible to accommodate all the released lines and hybrids in the research centers due to the required larger isolation distances in the courses of multiplication and maintenance breeding. The shortage forced the government to seek other ways to enhance production, and actions were taken to expand the parental seed production throughout the country. Thus, the RARIs and ESE and later some private seed companies were given the responsibilities of producing parent seed for themselves and for others. The multinationals remained in their hybrid seed production activities after introducing parent seed from abroad.

Earlier in 2008 the RARIs were commissioned to increase parental seed of the extensively popularized hybrids i.e., BH660 and BH540. Moreover, the task needed extra care and management that involved intensive labor and wider farm plots. Thus, it was recognized that the research centers alone could not shoulder the task. This forced the Ministry of Agriculture (MoA) to include the ESE as an additional responsible body for the multiplication of parental seeds. Some private seed companies and regional seed enterprises have also been entitled to parental seed multiplication. It is an important step forward, but needs clear decisions since the task is very sensitive and decisive in the commercial maize seed supply.

The quantity of parental seed ESE received from the research centers from 2002 to 2009 is shown in Table 1. The total parental seed supply in those eight years was only 246.2 t which could cover about 12,000 ha of hybrid certified seed multiplication plots. ESE started parental seed increase under contract with the Upper Awash irrigated farm in

2009 using the parental seed it received from the public research system. The 2009 off-season parental seed increase was intended to avail seed for the emergency certified seed multiplication program and didn't follow the standardized procedures in the seed class used for multiplication purpose. The seed used for the increase program was the parental seed ready for certified seed production. The actual standardized parental seed multiplication started in 2010 (Table 2).

Certified Seed Production

The certified seed production data from the last nine years doesn't show a constant trend. Although the adoption rate of improved varieties and the demand for their seed were believed to increase every year, the amount of seed produced doesn't follow this pattern. Many OPVs and hybrids were released in the period between the second and the third national maize workshops of Ethiopia. The total seed produced in the last nine years amounts to 44,623 t (Table 3). It is well noted that farmers gave priority for yield over any other attribute from a hybrid or an OPV whenever possible. Seed producers and companies in addition consider the production capacity of the parents which is largely dependent upon the pollen shedding capacity of the males and the seed yield of the female parents and their flower nicking behaviors. This led to the fast adoption of hybrids which yielded more commercial seed with relative ease and at the same time with higher productivity when the hybrid was used by the farmers. BH660 fulfilled both requirements. Farmers living in areas of relatively higher volumes and longer periods of rainfall duration strongly demand this hybrid. The hybrid has been also produced easily with easily distinguishable male and female plants. This is the reason why this hybrid took by far the highest share in the total production and sales of hybrids in the last nine years (Table 4).

The share of hybrids to the total seed produced increased from 65%, in 1992–2001 (Yonas and Kahsay, 2002) to 85.3% in 2003–2010 (Table 4). This may be due to the adoption of improved maize cultivars being concentrated in the high potential maize producing areas. Though there were many OPVs with reasonable yielding capacities in most high potential areas farmers considered them only as a last resort after the hybrid seed stock was depleted or not able to be accessed. The seed production plans in the ESE always considered the previous year's performance data in addition to the availability of parent/basic seed and contract multipliers. Hence, the seed production data indicate the cultivar preference of the small farmers.

Table 2. Parental seed increase 2010.

Parent	Area (ha)	Production (t)
A7033/F7215	8	7.2
1421e	4	5.4
SC22	3	2.9
GuttoLMS5	1	3.9
Total	16	19.4

Source: Ethiopian Seed Enterprise

Table 1. Summary of parental seed supplied to the Ethiopian Seed Enterprise by research centers (t).

Parent	2002	2003	2004	2005	2006	2007	2008	2009	Total
CML197	0.2	0.3	0.7	0.0	1.1	1.2	0.0	0.0	3.5
SC22	5.2	8.0	20.0	6.0	28.8	13.2	20.0	0.0	101.2
124b/113	8.0	0.0	5.0	2.5	12.4	1.0	4.5	2.4	35.8
1421e	0.0	0.0	3.0	1.7	2.0	7.3	9.2	2.0	25.2
1447b	0.0	0.6	0.6	0.5	0.5	1.0	0.0	0.0	3.2
A7033/F7215	0.0	0.0	0.0	7.0	7.4	0.0	8.9	0.0	23.3
CML144/CML159	1.0	0.0	0.0	4.0	4.6	1.9	0.0	0.0	11.9
CML176	0.0	0.0	0.0	0.0	1.6	0.7	0.0	0.0	2.3
GuttoLMS5	0.0	4.5	4.5	0.0	0.0	14.0	0.0	0.0	23.0
SC22/124b/109	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	3.8
NSCM411881/32	0.4	0.8	2.7	0.0	0.0	0.0	0.0	0.0	3.9
A7033	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.2
F7215	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	1.9
CML197	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	4.2
Total	14.8	14.6	36.5	21.7	62.5	44.1	42.6	9.5	246.2

Source: Ethiopian Seed Enterprise
NB: Parental seeds of BH660, BH670, BH540, BH543, BHQP542, BH541

Seed Enterprise

Nine local hybrids and seven OPVs were included in the certified seed production program in the last nine years but very few of them became a large proportion (Tables 4 and 5). Three hybrids, BH660, BH540 and BH140 accounted for more than 92% of the total hybrid seed produced by ESE in the period from 2002 to 2010. BH660 alone accounted for about 56% of the total. The merits of BH660 were discussed above. Though BH540 proved to be well adapted in the intermediate altitude areas and became very popular among the farmers living in those areas, due to its relative high yield and acceptable grain texture, however, its seed has not been produced in as large quantities as it had been intended. Since this hybrid is a single cross, its seed parent is less productive. The male parent also has short pollen shedding duration. The recently released three way hybrid, BH543 is a good alternative hybrid for BH540 but it could not withstand *turcicum* leaf blight, which necessitates positioning of this hybrid where the disease is not common. The case of BH140 is quite different from the above three hybrids. Its merit is that it is easily produced and has relatively higher seed yield than BH540 and has attracted contract seed growers because of its female parent, GuttoLMS5, which is an OPV. Its male parent, SC22, which is used as a female parent in BH540 seed production, was a better pollinator than 124b/113 which is the male parent of the same hybrid. The commercial hybrid, BH140, however, is a lower yielder and inferior in grain appearance. Thus, BH140 was produced in larger quantities to be used as a substitute to fill the supply gap left by BH540. BH140 was taken up by the farmers because BH540 seed was not produced in sufficient quantity.

Table 3. Summary of maize seed production in tons (2002–2010).

Year	Hybrids	OPVs	Total	% Hybrids	% OPVs
2002	1,007	1,519	2,525	39.9	60.1
2003	2,111	735	2,846	74.2	25.8
2004	3,739	1,027	4,766	78.5	21.5
2005	3,734	955	4,690	79.6	20.4
2006	5,543	897	6,440	86.1	13.9
2007	3,930	878	4,808	81.7	18.3
2008	3,076	213	3,289	93.5	6.5
2009	7,678	257	7,934	96.8	3.2
2010	7,263	62	7,325	99.2	0.9
Total	38,082	6,542	44,623	85.3	14.7
Annual average	5,440	935	6,375	85.3	14.7

Source: Ethiopian Seed Enterprise. OPVs = open pollinated varities.

Similar situations have been noticed in the case of OPVs. It seems that OPVs are demanded by the farmers of stressed environments. Only Katumani and A511 (both are very old varieties) were produced in a very large proportion to cover more than 72% of the total OPVs seed produced (Table 5). Therefore, their replacement with other superior varieties of similar adaptation zones is crucial.

The recently released Melkasa series varieties will help. It has been revealed from some field day impressions of the farmers that these varieties have the potential to replace Katumani and A511. Melkasa2 could be used instead of A511 while Melkasa4 can be used as an alternative for Katumani. The joint effort of CIMMYT, the Ethiopian Institute of Agricultural Research (EIAR) and ESE in promoting the drought tolerant maize

Table 4. The shares of the major hybrids in the 2002–2010 seed production.

Variety	Year of release	Seed produced (t)	% Share of total hybrids	% Share of total maize seed
BH660	1993	21,381	56.1	47.9
BH540	1995	8,535	22.4	19.1
BH140	1988	5,331	14.0	11.9
Total (3 hybrids)	–	35,247	92.5	79.0
Total (all hybrids)	–	38,082	100.0	85.3
Total seed		44,623	–	100.0

Source: Ethiopian Seed Enterprise

Table 5. The shares of the major open-pollinated varieties (OPVs) in the 2002–2010 seed production.

Variety	Year of release	Seed produced (t)	% Share of total OPVs	% Share of total maize seed
Katumani	1974	2,456	43.5	5.5
A511	1973	1,889	28.9	4.2
Total (2 OPVs)	1973–1974	4,344	72.4	9.7
Total (all OPVs)		6,542	100.0	14.7
Total seed		44,623		100.0

Source: Ethiopian Seed Enterprise

varieties including some of the Melkasa series varieties would be more fruitful if supported by intensive seed production and supply to target environments. Apart from the issues of short cycled drought tolerant varieties it is also necessary to consider some of the already released OPVs which are adapted to the non-stressed areas. Morka and Ghibe1 proved to be quite productive but their high yielding capacities have been masked by hybrids. Besides the varietal diversification concerns, the growing risk of total dependence of the farmers on seed companies every year for fresh seed stock supply necessitates the intensive popularization of these four OPVs and others as a safeguard measure.

The importance of quality protein maize (QPM) cultivars has been highlighted as a solution for malnutrition problems especially in areas of maize monoculture where people do not have other protein sources. It was expected that the first QPM hybrid (BHQP542) which was released in 2002 would have been taken up quickly and be demanded in great quantities. It was incorporated into varietal demonstrations in areas where children were suffering from protein malnutrition. However, despite a lot of efforts for its popularization, farmers didn't show enough interest in its adoption. They didn't consider the quality protein premium of the hybrid. The main reason behind this is that this hybrid showed inferior yielding capability when compared with that of BH540 and BH660, which are later maturing as compared to BHQP542. The traditional grain markets which are exercised in most maize producing areas are not also in a position to add a premium price due to this valuable attribute. As a result it is next to BH140 in varietal preference. In continued efforts some other QPM varieties have been released recently and some of them are included in the production and popularization activities of the ESE.

In general, the 2002–2010 seed production program included several hybrids and OPVs when compared with that of the 1992–2001 period with an increase of 24% in average total volume. In the period between 1992 and 2001 average annual maize seed production was 4,843 tons (Yonas and Kahsay, 2002) while 2002–2010 records show 6,375 t (Table 3). The share of OPVs declined from 35% to 14.7% (Table 5). This shows that maize seed production by the ESE didn't show reasonable progress. One of the major reasons behind the low production was the halt in the use of the irrigated farms of Upper Awash under the contractual seed multiplication. The 2000 and 2001 hybrid seed multiplication records were the highest ever. It was recorded that the irrigated maize seed production which started in 1997 reached the peak in 2000 and 2001 (Yonas and Kahsay, 2002). Recent activities to resume the contract with Upper Awash state farms and include other state owned irrigated farms into seed multiplication contracts would enhance the volume of the seed available for the farmers.

Seed Extension, Varietal Popularization and Quality Assurance

ESE has been dealing with seed extension and varietal popularization of its products in an organized manner since 1994. The three strategies of seed extension and varietal popularization in the ESE are:

- Varietal demonstrations and field days,
- Discussion forums with small farmers on the seed supplied by the enterprise, and
- Field evaluation work on the performance and management of the varieties in the small farmers' holdings.

New varieties have been introduced to new areas through varietal demonstrations and field day operations. Both hybrids and OPVs are included in the varietal popularization work. In many cases small farmers entered into contractual seed multiplication with the enterprise after they were convinced to grow the varieties demonstrated at field day events. For maize this system didn't come into effect due to quality concerns. It is very difficult to keep ample isolation distances within the small farmers' holdings since the individual plot sizes are small, and are surrounded with numerous small plots owned by many small farmers. However, it has been proved recently with the activities of other seed companies that it is possible to grow hybrids in contract with clustered small farmers' holdings. Nevertheless, quality will remain the main concern until farmers develop enough knowledge and skill in techniques of hybrid maize seed production.

The knowledge and perception of quality in maize seed grew considerably in the last decade among both contract seed multipliers and seed users. Many small farmers are now well aware of quality attributes to the extent of the morphological characteristics of the hybrids they use. ESE also continued with its own internal quality assurance activities even after the introduction of the national seed certification system. Most of the internal quality attention lies in the production activities. At present, seed quality control and certification activities are not done properly. Due to capacity limitations, not every formal seed multiplication plot is inspected and not every seed lot is certified.

Seed Sales and Distribution

The Ethiopian seed industry which was initially structured in the late 1970s to serve the then large scale state farms didn't consider the seed marketing component as it should have been. Thus, the seed sales and distribution remained the weakest and least organized segment in the ESE operations (Table 6). Maize seed followed the same pattern as all other crops though it was proved that hybrid maize seed sales could be done in a different manner. Due to excessive seed demand for hybrids many farmers intended to purchase hybrid seed from the ESE seed processing plants and warehouses. Most farmers used to access ESE brand seeds through farmers' cooperatives unions (FCUs) and their respective regional Bureau of Agriculture (BoA). Some farmers were also organizing themselves in groups and sent representatives from inaccessible areas to purchase maize seed. However, the enterprise still sticks with the sales and distribution system using third parties especially in retail for all crop seeds.

In the past decade most major activities related to seed sales and retail were conducted by the BoAs and FCUs. Development Agents who were assigned to work with the small farmers at *kebele* and *woreda* level used to be responsible for grass-root demand assessment on a varietal basis. The seed demands they collected were forwarded to the *woreda* BoAs offices. The next step was to compile the *woreda's* demands by their zonal departments which were forwarded to the BoAs. The agricultural input marketing directorate of the MoA received the same from each region and the national seed demand was endorsed. This was done in the time frame between November and March every year.

Similar procedures have been followed in the seed supply side. Private seed companies as well as the ESE used to report the amount of certified seed they could supply in the specified year. The report is submitted to the agricultural input marketing directorate of the MoA in the period of January to March. The data on the total available seed stock is compiled at national level. Volume and varietal allocation is done between the regions by the directorate. The BoAs and the seed companies are then notified to pursue with the next steps on their behalf. This is done in the month of March. ESE usually advises the BoA from which seed warehouse they should collect the seed they are entitled to purchase, and the current seed price.

The actual seed purchase coordination has been the responsibility of the zonal agricultural departments. After receiving their share from their BoA the zonal departments assign eligible FCUs to purchase and distribute the seed to the farmers living in the area of their activities. The cooperative unions then do the actual seed purchase, transport and retail. Final prices include transportation and administrative costs of the unions. This sales system worked well in the regions where strong and active FCUs operated. In the regions where such cooperative unions are at their infant stage the BoA themselves handle the seed purchase, transport and retail activities.

Maize seed prices have been determined at the same time when the prices of seeds of other crops have been determined. A very small profit margin (< 5% of the total production cost) is added and the warehouse gate prices are fixed. Owing to their lower yielding capacities higher procurement prices per 100 kg have been demanded for short cycle OPVs like Katumani and Melkasa varieties by the contract seed multipliers. Thus, their selling prices are a little bit more than the other OPVs. ESE's seed selling prices have been very low (Table 7). Despite the great efforts to keep the prices of all seed lower, it has been repeatedly seen that the

Table 7. Maize seed selling prices of 2001–2010.

	Birr t^{-1}			Birr ha^{-1}		
Years	Hybrids	OPVs	Short cycle OPVs	Hybrids	OPVs	Short cycle OPVs
2002	5,600	1,800	1,960	140	45	49
2003	5,780	2,220	2,400	145	56	60
2004	5,780	2,220	2,400	145	56	60
2005	5,780	2,220	3,000	145	56	75
2006	6,500	2,350	3,000	163	59	75
2007	7,200	2,500	3,500	180	63	88
2008	8,200	3,750	4,000	205	94	100
2009	9,890	4,430	4,720	247	111	118
2010	12,500	6,100	5,500	1,682.5	702.5	762.5

Source: Ethiopian Seed Enterprise
OPVs = Open-pollinated varieties.

Table 6. Maize seed sales records 2002-2010 (t).

Varieties	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	Annual average
Hybrids	2,286	5,229	4,369	4,316	3,508	5,055	3,616	2,966	4,471	35,815	3,980
Open-pollinated varieties	283	684	697	563	1,157	419	578	782	242	5,405	601
Total	2,568	5,913	5,065	4,879	4,665	5,475	4,193	3,748	4,713	41,221	4,580

Source: Ethiopian Seed Enterprise

price is hiked when it reaches the small farmers. FCUs considered the seed as any other commodity, subject to a large profit margin. The other problem of high retail prices is the association with the sales system itself. FCUs and BoA used to collect maize seed from different sources at different purchase prices. In most cases FCUs set average prices of seed of different enterprises at retail. In regions where the BoA was involved in seed retail the final selling price is determined differently usually lower than the FCUs.

The average annual maize seed sales volume between 2002 and 2010 was higher when compared with that of the period of 1992–2001. In the period between 2002 and 2010 the average annual hybrid maize seed sales surpassed that of the 1992–2001 by 74.1% while the records for the OPVs sales show a decline by 56.3% and the total average maize sales increased by 37.8%. The share of hybrids to the total maize seed sales in the last nine years rose to 86.9% from that of 68.8% in 1992–2001 (Yonas and Kahsay, 2002). The three hybrids, BH660, BH540, and BH140, covered 95.1% of the total hybrid sales while the two OPVs, Katumani and A511 shared 86.0% of the total OPV seed sold (Tables 8 and 9).

ESE maintained its maize seed packing sizes and packing materials. Maize seed was packed for sale in polyethylene bags of either 12.5 or 25 kg capacities to suit 0.5 or 1.0 ha, respectively. It is proved from the results of several field survey activities conducted

Table 8. Shares of the major hybrids in the 2002–2010 seed sales of the Ethiopian Seed Enterprise.

Variety	Seed sold (t)	% Share of total hybrids	% Share of total maize seed
BH660	20,198	56.4	49.0
BH540	7,201	20.1	17.5
BH140	6,669	18.6	16.2
Total (3 hybrids)	34,068	95.1	82.6
Total (all hybrids)	35,815	100.0	86.9
Total seed	41,221	–	100.0

Source: Ethiopian Seed Enterprise

Table 9. The shares of the major open-pollinated varieties (OPVs) in the 2002–2010 seed sales.

Variety	Seed sold (t)	% Share of total OPVs	% Share of total maize seed
Katumani	2,541	47.0	6.2
A511	2,106	39.0	5.1
Total (2 OPVs)	4,646	86.0	11.3
Total (all OPVs)	5,405	100.0	13.1
Total seed	41,221	–	100.0

Source: Ethiopian Seed Enterprise

by the enterprise that most of the small farmers who used ESE's maize seed usually cultivated 0.5 ha of land for each variety. However, recent observations show that smaller packing sizes are important. Seed packing sizes, as low as 5–10 kg are suggested by many farmers. Although most of the seed of other crops which was distributed to the small farmers has not been treated with chemicals, all the hybrid maize seed has been treated with both fungicides and insecticides before distribution. The amount of maize seed sold in the last nine years is shown in Tables 7, 8 and 9.

The total seed sold was greater than the total seed produced in the specified period. The production data (Table 3) shows the amount of raw seed produced each year. The volume of the seed sold each year was that of the previous year's production plus carry over stock. Hence, the 2003 sale was largely part of the 2002 production. The 2002 seed sale was the lowest since 2001. The reason being that farmers declined to use improved seed because the 2001 grain price of maize was the lowest in the decade which discouraged seed users. Nevertheless, in 2003 the grain price rose due to lower grain availability which in turn stimulated the seed demand. In 2003 the seed sales data shows the maximum in the last nine years.

The contribution of ESE's maize seed supply to the maize farming community was very low. In the period of 2002–2010 ESE distributed a total of 41,221 t of maize seed which was estimated to cover 1,648,820 ha. The annual average coverage was 183,202 ha, which was very low when compared with the total cultivated maize area, about 2.1 million hectares, estimated by the Central Statistical Agency (CSA, 2010). In 2010 ESE's total maize seed sale was 4,713 t which covered about 188,536 ha. ESE's supply was only 10.6% of the total maize seed used in the year 2010. The shortfall was further amplified by the varietal structure of the seed supply where most of the seed was of hybrid cultivars which was intended to be used only once. Being the main seed supplier, where about 90% of the national seed supply originated, the above figures show that many more seed suppliers are needed. At present the shortage in hybrid seed supply causes some other very serious problems. Small farmers in desperate need for the seed were buying fake seeds from the market and many fraudulent crimes were filed in many parts of the country.

Hybrid Variety Development Efforts

Besides its efforts in the multiplication of the parent seed of the hybrids developed by the EIAR, ESE continued its activities of developing its own hybrids over the past 25 years. In 2005 ESE released the single cross hybrid, ESE203 (Toga) for commercial production in the mid-altitude sub-humid maize agro-ecology of Ethiopia. Currently, the ESE is undertaking various activities including multi-location testing of a range of single and three way cross hybrids, some of which are in the pipeline for a possible release in the next few years. Other breeding activities like germplasm development, diallel cross formation, pre-national and national variety trials, on-station and on-farm verification trials, seed increase of parental inbreds are among the main activities being carried out on a regular basis. In addition, ESE is also enriching its maize germplasm base by introducing materials from international maize centers prominently from CIMMYT. The results of national and pre-national variety trials conducted during the periods of 2004–2010 have indicated the possibility of identifying high yielding hybrids.

PR1, PR13 and BH540 were the top three hybrids that performed well across the three years (2004–2006) based on the average grain yield of 7.14 t ha^{-1}, 6.77 t ha^{-1} and 6.57 t ha^{-1}, respectively. In addition, seven ESE hybrids performed similarly with the commercially released check (data not shown). Although, it could be possible to release PR1 and PR13 as commercial hybrids, as they had shown comparable yields with the check, the release of single cross hybrids is not advantageous for ESE. This is because of the low seed yield expected from the female parent as well as the current seed pricing guideline which assumes similar selling pricing across all classes of hybrids. As a result the direction of the ESE maize breeding is geared towards the release of three way cross hybrids. After 2006, development of new three way cross hybrids began as the main target for ESE's maize research and product development initiative.

Eighteen ESE three way cross maize hybrids, together with two released standard checks, were evaluated for grain yield over a period of four years (2007–2010) across five locations (Hawassa, Bako, Upper Bir, Gonde and Kunzila (W. Gojjam)), in a total of 20 environments in Ethiopia (data not shown). These three-way hybrids were selected based on their relative yield performance among the different experimental hybrids developed by the ESE maize breeding program. All the hybrids are categorized under the medium maturity group (between 140 and 145 days) and their broad adaptation zone is mid-altitude sub-humid which includes areas with an elevation range of 1,000–2,000 masl and an annual rainfall between 1,000 and 1,200 mm. Among the hybrids tested from 2007–2010, maize hybrids EC237, BH543 and EC255 were the top three hybrids that performed well across the four years based on the average grain yield of 7.02 t ha^{-1}, 6.79 t ha^{-1} and 6.77 t ha^{-1}, respectively. Maize hybrids, EC225, EC247 and EC296 were also among the top hybrids that performed well across the four years based on the average grain yield of 6.08 t ha^{-1}, 6.05 t ha^{-1} and 6.04 t ha^{-1}, respectively.

From the results, it is recommended to evaluate EC237, EC225, EC247, and EC296 under farmers' managed plots (on-farm verification trials) across different locations for a possible release of either of the candidates in 2012. Similarly, it is recommended to initiate the evaluation of these candidate varieties for their suitability for seed production.

Finally, the results of the ESE's maize research conducted over the years indicates the availability of alternative maize varieties for the Ethiopian farmers. ESE's maize breeding activity can be considered as a complement to the national maize improvement program to underpin the effort to release better hybrids in a relatively short product cycle.

Critical Issues

In Ethiopia the public seed sector is the main producer and supplier of maize seed. It has been revealed from past records that seed production and supply of both hybrids and OPVs are very low when compared with the huge demand from different users. The private sector, on the other hand, hasn't developed to complement the demand gap. The activities of the multinational seed companies are also limited to the operations of the Ethiopian Pioneer Hi-Bred Company. Therefore, the maize seed supply system needs further strengthening and improvement. Many structural and organizational changes may be needed. Some of the most critical issues related to the public sector are discussed below.

Varietal development, release and related issues

The public research system has released several hybrids and OPVs but few of them have been absorbed by the seed production system. In addition, some varieties which entered into the seed production were withdrawn from the system. It is natural that varieties are obsolete or are withdrawn from seed production provided that they are replaced with complementary or superior alternatives. Rapid replacement of varieties are among the most important issues. All the necessary arrangements like popularization of already released varieties, the release of more productive local hybrids and attracting more foreign seed companies deem necessary. The other area of concern in this regard is the suitability of the hybrids in the production cycle. Some hybrids have proved to be productive when their commercial seed is used by farmers, but it is difficult to produce their certified seed. Problems in seed production related to flower nicking, pollination capacity and female seed yield needs to be addressed. Seed related research which aims at a complete package of seed production should accompany variety release.

Parental seed availability issues

The recent move in commissioning ESE and others for the parental seed multiplication is an important step in availing basic seed for other seed companies. However, a strong seed quality control system should be in place in order to produce quality basic seed. The ESE has a rich experience in seed production and can handle the responsibility in a better way.

Certified seed production issues

The public sector maize seed production was very much limited in volume in the past. Several reasons could be cited for this limitation. The main reasons were the shortage of parental seed and lack of proper seed multiplication sites. Although the supply in parental seed has been improved, certified seed production is also expected to be enhanced with the intensification of irrigated seed multiplication. ESE needs to be strengthened financially and structurally to exploit the opportunities.

Seed marketing, distribution and pricing issues

The viability of any seed program is measured among others by its capability to produce quality seed on time at an affordable price. The public sector has committed to do so and succeeded especially in the area of price reduction. Nevertheless, small scale farmers could not benefit from this effort. This is partially due to less attention being given to the market segment of the seed industry. The present seed marketing arrangement would not be long lasting in addition to the various gaps that brought about serious problems to the seed system. Especially as unfair price hikes and several fraudulent crimes were recorded in the past. The arrangement for an effective seed marketing system that involves responsible bodies is an immediate requirement.

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Small Scale Farmer Based Hybrid Maize Seed Multiplication: Experience of Oromia Seed Enterprise

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Introduction

Agriculture dominates the economy and livelihood of Ethiopians in general and the Oromia region in particular. It accounts for 65% of the regional gross domestic product (GDP). Large scale state and private farms, and small scale farms are the common types of farming systems in the region. The land holding of the small scale farmers ranges from 1 to 3 ha per farm family. Maize grain production and area in Oromia comprises about 59% and 56% of the total production and land area of Ethiopia, respectively (CSA, 2010). Therefore, any factor which has a positive impact on maize production has the potential to improve the socio-economic wellbeing of the people of the country as well as the region. Of all farm inputs, high quality seed of adapted varieties and planting materials exert the most profound influence on agricultural productivity. The recognition of this fact has led to numerous efforts in Oromia to develop a sustainable seed production and supply system. These efforts have created a high degree of awareness about the importance of seed among all categories of farmers, and have made contributions to the overall national food security efforts. Indeed, seed security has become synonymous with food security. But in spite of the advances made so far, many small scale farmers have not adequately benefited from the successes of modern crop improvement such as the production of hybrid maize varieties. Farmers of the region have been complaining about the shortage of seeds over the last decades and continue to face productivity uncertainties associated with the use of unsuitable seeds. Even though the formal seed system has made significant effort to satisfy seed demand in the region, small scale farmers' demand has not been satisfied. Missing the involvement of small scale farmers in the production of hybrid maize seed partly contributed to the seed shortage. In recognition of the importance of the participation of small holder farmers in hybrid maize seed multiplication, Oromia Seed Enterprise (OSE) began hybrid maize seed production on small scale farmers' fields under contractual agreement in 2008. Therefore, this paper highlights the general status of small scale farmer based hybrid maize seed multiplication activities in Oromia National Regional State and presents recommendations that could help to sustain the system and to further scale it up.

Approach Followed by OSE for Hybrid Maize Seed Production on Small Scale Farmers' Fields

Since its establishment, OSE has designed its own small-scale farmer-based hybrid maize seed multiplication approach. There were a series of activities that were carried out starting with identifying zones and districts which had interest to carry out small scale farmer-based hybrid maize seed multiplication in their respective zone and district.

Identifying zone and district

Hybrid maize seed multiplication needs close supervision and technical skills. Therefore, support from agronomists at zonal and district agricultural offices and development agents (DAs) at a village level was important. Accordingly, OSE identified suitable zones and districts which had well organized farmers' groups and had the interest to carry out hybrid seed multiplication activities (Table 1).

Site selection

Seed multiplication sites were selected based on accessibility and suitability.

Farmer selection

Farmers, who were willing to offer their land and labor for the seed multiplication, buy the agricultural inputs such as fertilizer and different chemicals were selected. The contractual agreement which governed the two parties was signed between OSE and farmers' cooperatives. After the agreement, the basic seeds for the selected farmers were supplied either on a cash or credit basis.

Clustering farms

The other prerequisite for seed multiplication was clustering the small farms to a minimum size of 10 ha per village. This approach helped in the supervision of the seed fields in an organized manner within a short period of time. Farmers also obtained technical advice and amended any defect that was observed during inspection.

Training

Training was organized to upgrade the technical capacity of DAs and supervisors of the districts. The training sessions were focused on hybrid maize seed production and its quality assurance procedures. Training was also organized for participating farmers at the village level.

Table 1. Hybrid maize seed multiplication sites and their locations in Oromia.

Part of the region	Zone	District	Mode of production
Eastern Oromia	East Hararghe	Jarso, Babile	Irrigation
	Arsi	Ziway-dugda, Jeju, Tiyo	Irrigation
Rift valley	East Shewa	Boset, Fentalle, Bora	Irrigation
	West Arsi	Arsi-egele	Rain-fed + Irrigation
South-east Oromia	Bale	Berbere, Delo-menna	Irrigation
Western Oromia	East Welagga	Sibu-sire, Boneya-boshe, Digga, Wayu-tuka, Gidda-ayana, Gudeya-bilaa	Rain-fed + Irrigation
	West Shewa	Ilu-gelan	Rain-fed
	HG. Wellagga	Hababo-gudru, Gudru, Jimma-geneti, Amuru, Jimma-rare	Rain-fed
	Kelem Welegga	Seyyo	Rain-fed
South-west Oromia	Jimma	Omo-nadda, Tiro-afeta, Qarsa, Manna, Sekka-chekorsa, Limu-sekka	Rain-fed + Irrigation
	South-west Shewa	Ammaya	Irrigation

Source: OSE, 2010.

Shelling services

Shelling service was supplied to farmers at a reasonable price by OSE. The cost of shelling service covers only the running cost. The seed shelling cost was deducted from the raw seed payment.

Quality assurance

Close supervision, field inspection and strong technical support have been rendered from planting to pre- and post-harvesting operation by OSE's inspector agronomist, zonal agricultural expert and DAs. The field inspections were usually carried out during planting (to ensure appropriate male to female ratio), flowering (to ensure proper detasselling), male parent removal (to ensure complete male parent removal) and harvesting and packing (to ensure proper cob sorting and moisture content). Formal seed quality control activities have been carried out by the Asella and Ambo seed quality control and certification laboratories. Germination and physical purity tests were also done by internal laboratories for quality certification.

Packing material supply and raw seed transportation

OSE supplied packing materials to the seed growers ahead of harvesting. The raw seed was packed in the supplied jute sacks with 100 kg net weight and stored in centralized temporary or cooperative's storage facilities. The germination capacity of the raw seed was also tested before transporting to OSE's processing centers.

Raw seed pricing and marketing

The price of the raw seed ranged from 600 to 700 Birr per 100 kg in the last three production seasons. OSE has been paying the small scale farmers at their farm gate. The market for the raw seed has been secured by the agreement made between the primary cooperative and OSE. Whatever fluctuation there is in the price of maize grain, the fixed hybrid maize raw seed price will not be affected.

Saving seed

The other unique feature of such small scale farmer based hybrid maize seed production is that OSE has allowed farmers to save up to 5% of the hybrid seed they have produced to use for grain production.

Achievements

Area under production

Area under hybrid maize seed production has been gradually increasing from year to year. This is due to the benefits that farmers have obtained from the business. The hybrid maize seed multiplication area under small scale farmers' holdings was about 385 ha in the 2008/09 off-season. It was increased to about 844 ha in the 2009 main-season. In the 2009/10 off-season the hybrid maize seed multiplication area on small scale farmers' holdings were drastically increased to 1,558 hectares. This, almost twofold, area increment was due to the crash program undertaken on hybrid maize seed multiplication activities to alleviate the shortage of hybrid maize seed in the region as well as in the country. The area under hybrid maize seed multiplication on small holder's fields was about 745 hectares in the main-season of 2010. The area reduction compared to the previous year was done deliberately to avoid over-production and carry over seed in subsequent season (Table 4).

Seed recovery

The seed recovery rate in the first season from farmers' hybrid maize seed production was about 0.8 t ha^{-1}. But the recovery rate has been gradually increased in subsequent seasons. It reached 1.5 t ha^{-1} in the 2010 production season and is expected to grow to 2 t ha^{-1} in 2011. This is due to the experience developed, farmers' interest and commitment to stay in the business, and the increased monitoring and evaluation of OSE (Tables 2 and 3).

Revenue generated by farmers

Small scale farmers who participated in hybrid maize seed production have generated a substantial amount of income. Farmers also used hybrid maize seed for maize grain production and benefited from the high yield of the hybrids. OSE has paid about 30.3 million Birr (ETB) to small scale farmers who have been engaged in hybrid maize seed production activity since 2008/09. The raw seed price was 600 ETB per 100 kg in 2008/09. The raw seed price of hybrid maize has been increased to 750 ETB per 100 kg in 2010/11. Such an increase in the raw seed price has motivated the farmers to stay in the business and work harder (Table 4).

Conclusion

Predominantly, it was believed that small scale farmers could not multiply hybrid maize seed. However, the experience of OSE over the past three years has shown that small scale farmers can produce quality seed with close supervision of agricultural experts. Since the farmer uses his family labor and makes frequent follow up of the day-to-day activities quality seed can be produced with relatively low cost. The average land holding of small scale farmers is generally small. Clustering such small holdings is very crucial to produce quality hybrid maize seed.The current achievement on small scale

Table 2. Small scale farmers' hybrid maize seed multiplication achievement (2008/09–2010/11).

	Irrigation 2008/09			Rain-fed 2009			Irrigation 2009/10			Rain-fed 2010			Irrigation 2010/11†		
Variety	Area (ha)	Yield (t)	SR (t ha^{-1})	Area (ha)	Yield (t)	SR (t ha^{-1})	Area (ha)	Yield (t)	SR (t ha^{-1})	Area (ha)	Yield (t)	SR (t ha^{-1})	Area (ha)	Yield (t)	SR (t ha^{-1})
BH543	134.3	137.3	1.0	0.0	0.0	0.0	207.3	318.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0
BH140	251.0	170.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BH660	0.0	0.0	0.0	812.2	789.9	1.0	1,348.2	1,739.9	1.3	745.3	1,131.2	1.5	120.0	240.0	2.0
BH542	0.0	0.0	0.0	32.0	68.8	2.2	0.0	0.0	0.0	0.0	0.0	0.0	16.0	32.0	2.0
Wanci	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.3	0.1	0.0	0.0	0.0	0.00	0.0	0.0
Total	385.3	308.0	0.8	844.2	858.7	1.0	1,558.4	2,058.4	1.3	745.3	1,131.2	1.5	136.0	272.0	2.0

† Yield is an estimation and the data presented here do not include certified seed produced by OSE on its farms and large scale farms.
SR = seed recovery

Table 3. Small scale farmers' hybrid maize seed production by area, yield and seed recovery rate.

	Irrigation (2008/09)	Rain-fed (2009)	Irrigation (2009/10)	Rain-fed (2010)	Irrigation (2010/11†)
Total area (ha)	385.3	844.2	1,558.4	745.3	136.0
Raw seed purchased (t)	308.0	858.7	2,058.4	1,131.2	272.0
Seed recovery rate	0.8	1.0	1.3	1.5	2.0

†Yield is an estimation.

Table 4. Revenue generated by small scale farmers who have engaged in hybrid maize multiplication (2008-2010/11).

	Irrigation (2008/09)	Rain-fed (2009)	Irrigation (2009/10)	Rain-fed (2010)	Irrigation (2010/11†)	Total
Total area (ha)	385.3	844.2	1,558.4	745.3	136.0	3,669.1
Basic seed used (t)	9.6	21.1	39.0	18.6	3.4	91.73
Raw seed purchased (t)	308.0	858.7	2,058.4	1,131.2	272.0	4,628.3
Raw seed price (ETB/ton)	6,000.0	6,000.0	6,500.0	7,000.0	7,500.0	
Revenue††	1,848,042.0	5,152,164.0	13,379,600.0	7,918,120.0	2,040,000.0	30,337,926.0

†Yield is an estimation, ††Revenue = Raw seed purchased (t) × raw seed price (ETB/ton) per season, ETB = Ethiopian Birr.

farmers' field hybrid maize seed multiplication which has been observed in Oromia is not complete by itself. It needs further reinforcement of farmers' technical capacity, and trust on the activity and business. The seed recovery is by far lower than what it should have been. It is associated with low productivity and farmers' being reluctant to sell to OSE all seed which has been produced. Farmers tend to save more seed than they need for their farm. They used to sell the hybrid seed to the neighboring farmers and relatives. In addition, there has been a tendency of using lower fertilizer rates than recommended. Therefore, farmers' technical capacity should be reinforced with rigorous training and coaching by seed experts. In addition, farmers need to understand that they should not kill the hen that lays the golden egg. Double production cycles within a year have played an important role in attaining hybrid maize seed security in the region. Therefore, such double cropping practices need to be sustainable.

Opportunities

Government policy direction is in support of agriculture and small scale farmers. Three development agents have been assigned to each farmer's administration unit of the rural part of the region. There are also credit facilities for agricultural inputs. The attractive grain market has also a positive impact on maintaining hybrid maize seed production business. There are also a lot of partner organizations in support of small scale farmers' hybrid maize seed multiplication. Among the major stakeholders CIMMYT, ICARDA and Alliance for Green Revolution in Africa (AGRA) are in support of seed security at farm level. The local seed business project which is being carried out with support of the Netherlands Government has also been contributing to small scale farmer based seed production and marketing in general. Farmers have enjoyed the income obtained from hybrid seed production. So they are eager and willing to keep the business going. Farmers have also developed technical skills in hybrid maize seed production that is very important to produce quality seed. The other important opportunity to keep up the business is high demand for hybrid maize seed in the region as well as in the country. Currently, more than 1 million ha of land is allotted for maize production in Oromia alone, and this large area demands more than 25,000 t of maize seed per annum.

Challenges

Maize Streak Virus (MSV) was one of the major biotic factors that contributed to low productivity of hybrid maize seed production in small scale farmers' fields under irrigation in the off-season in the western part of the region. It was one of production constraints that was faced in the last five production cycles particularly in relation to BH660 and BH543 seed production in small scale farmers' fields in the off-season. Maize Stalk Borer was also another biotic factor that caused low production in hybrid maize seed. Overlapping maize seed crop harvesting operations with the onset of Belg rain is one of the challenges that had been faced during irrigation based hybrid maize seed production on famers' fields. Maize seed drying operations became difficult during this season and high moisture had a negative impact associated with seed quality. High moisture content of the raw seed contributed to the deterioration of seed due to heat development and insect damage and consequently led to viability loss.

Farmers have been producing maize on the same field for many years. Such mono-cropping trends lead to depletion of soil fertility. Maize is by its nature a heavy feeder of nitrogen. So, it doesn't perform very well in poor soils. The productivity of hybrid maize seed production in the small scale farmers will reduce unless reversed by crop rotation and other appropriate management practices.

Future Direction

It is very difficult to work with unorganized individual farmers especially for hybrid maize seed production. There must be a bylaw that governs all individual farmers who engage in the seed production business. Farmers have different interests. As a result, it is very difficult to manage these individual interests. Therefore, organizing farmers who have the same interest under a seed producer cooperative (SPC) has paramount importance. All members of the SPC have to agree on their organizational law and regulation. They also need to abide by the agreement that has been made between their SPC and contract provider such as OSE. Knowledge and skill of seed production technique is crucial to producing high quality seed. There must be continuous and refresher training to small scale farmers who are supposed to engage in the seed production. Practical guidelines should be developed in local languages that farmers can follow in each activity of hybrid maize seed production. The guideline helps to coach farmers in every activity and take corrective measures in the seed quality assurance process from site selection to harvesting.

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Overview of Seed Production in Amhara Region: The Case of Hybrid Maize

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Introduction

The Amhara region of Ethiopia is blessed with huge natural resources such as water, cultivable land and labor. Thus, it is highly suitable for agricultural production. If this enormous potential of the region for food crops production and livestock husbandry is managed properly, it could alone sustainably feed the current 74 million population of Ethiopia.

The Amhara National Regional State (ANRS) occupies much of the north-western and north-eastern parts of Ethiopia. The total area is about 0.16 million km^2 constituting about 14.4% of the total area of the country. According to the Bureau of Finance and Economic Development projection estimate of 2006 (ABFED, 2006), the current total population of the region is estimated to be 20 million. The vast majority of the population in the region is engaged in agriculture for their livelihood, which indicates that agriculture is the backbone of the regional economy.

Crop production and animal husbandry are the major activities undertaken in the region. Cereals, pulses, oil crops, fiber crops, fruits and vegetables are the crops grown in different parts of the region. Of the total area of the region, about 4.2 million hectares of land were used for crop production in the 2010/11 cropping year. In the same year, the total volume of crop production reached 6.5 million tons. In this regard, the Amhara region constitutes about 34.9% and 33.2% of the national area covered by crops and total production, respectively (CSA, 2010).

In the region, utilization of improved seeds is at a very low level and only 3.5% of the total cultivated land was covered by improved seeds in the 2009/10 cropping year mainly due to the limited capacity of seed producers operating in the region. In the same year, the area covered by improved seeds of cereals and pulses in the region was about 146,046 hectares. Relatively, the area covered by improved seeds of maize (hybrid maize) was high which accounted for 35% of the land covered by maize in the region. Overall, productivity of cereal crops is extremely low (about 1.5 t ha^{-1}) and calls for the urgent use of improved seeds with full application of the recommended agronomic practices (ABA, 2010; CSA, 2010).

To meet the growing demand of improved seed, the Amhara Seed Enterprise (ASE) was established by the ANRS in 2009 to supply different classes of seed of various cereals, fruits and vegetables and forage crops to end users. Besides its own farm, ASE uses farms of government and private organizations as well as small-scale farmers' fields to multiply quality seed and promote seed technology in the region. In this paper, progress made in hybrid maize seed production by ASE in the region is discussed.

Hybrid Seed Production in the 2010/11 Cropping Year

ASE has executed a well-coordinated hybrid seed production on farmers' fields, private farms and its own farm in the main-season of 2010/11. The small-scale farmers' fields were clustered to obtain a larger area in one location (Fig. 1). Priority was given to hybrid maize seed multiplication and it covered about 4,292 ha of land with the expected production amount of 8,738.5 t. The hybrid maize varieties for certified seed production included BH660, BH540 and BH543 (Tables 1 and 2). Furthermore, parental lines of the hybrids were multiplied and crossed to obtain pre-basic and basic seeds (Table 3). The seed source for all parental lines was the National Maize Research Centre at Bako. The total volume of hybrid seeds produced and cleaned

Figure 1. A cluster of more than 340 ha of small scale farmers' plots.

Table 1. BH660 hybrid seed multiplication in Amhara region by the Amhara Seed Enterprise (2010/11).

No.	Name of district	Expected yield (t)	Seeds collected (t)	Cleaned seeds (t)
1	Womberma	3,867.4	2,952.8	
2	Burie Zuria	944.1	697.6	
3	Dembecha	63.3	20.8	
4	Jabitehnan	166.5	77.7	
5	Yilmana Densa	88.1	51.8	
6	Burie town	135.9	75.5	
7	South Achefer	367.7	152.8	
8	Basoliben	32.3	14.1	
9	Debre Elias	250.0	162.3	
10	Dejen	25.0	17.9	
11	Gozamin	21.6	10.3	
12	Machakel	234.0	139.9	
13	Ankesha	67.3	56.0	
14	Dangla town	3.0	2.4	
15	Guangua	132.0	97.6	
Total		6,398.2	4,529.5	4,350.1

Table 2. BH540 and BH543 hybrid seed multiplication in the Amhara region by the Amhara Seed Enterprise (2010/11).

No.	Name of district	Variety	Expected yield (t)	Seeds collected (t)	Cleaned Seeds (t)
1	Takussa	BH540	902.5	723.0	
2	North Achefer	BH540	322.0	120.0	
3	Gonjkollela	BH540	4.0	1.6	
4	Mecha	BH540	170.3	99.5	
5	South Achefer	BH540	136.0	50.3	
6	Jabitehnan	BH540	24.0	9.2	
7	Dera	BH540	35.3	36.4	
8	Fogera	BH540	13.2	8.9	
9	Wereta town	BH540	5.6	3.1	
10	East Estie	BH540	6.0	1.2	
11	Libokemkem	BH540	1.0	–	
12	Alefa	BH540	36.8	27.5	
13	Chilga	BH540	12.3	18.3	
14	Denbia	BH540	19.6	24.9	
15	Ankesha	BH540	95.0	80.6	
16	Efratana Gidem	BH540	32.1	36.5	
17	Kobo	BH540	94.3	35.4	
18	Dawa Chefa	BH540	34.8	20.0	
19	Dangur	BH540	100.0	63.6	
20	Womberma	BH543	105.0	82.7	
Total			2,044.8	1,360.1	1,276.6

Table 3. Parental lines of hybrid seed multiplication in the Amhara region by the Amhara Seed Enterprise (2010/11).

Name of district	Parent	Expected yield (t)	Seeds collected (t)	Cleaned seeds (t)
	A7033/F7215	89.7	58.6	55.1
	142-1-e	11.5	11.7	9.5
	SC22	36.4	9.0	7.4
Chagni	124b113	15.7	18.1	17.0
	A7033	10.8	5.9	5.4
	F7215	26.4	20.7	19.2
	Total	190.5	124.0	113.6

reached 6,096.2 t and 5,740.3 t, respectively. More than 85% of hybrid seed multiplication was conducted on farmers' fields through contractual agreements. A total of 36 districts were involved in the hybrid maize seed production activity in the region. The details are shown in Tables 1, 2 and 3.

The major activities undertaken during the hybrid seed production included the following:

- Proper land selection in cluster farms
- Proper selection of dedicated farmers
- Training of farmers and experts
- Provision of improved seeds
- Field monitoring and technical support
- Field inspection by quarantine section
- Collection of hybrid seeds from the threshing floor
- Payment of seed costs
- Transportation of seeds
- Temporary storage of seeds
- Seed cleaning, chemical dressing and distribution to the farmers

Conclusions

In general, the major factors that have contributed to the success of hybrid maize production of ASE in its first year of inception are: favorable growing season, proper selection of suitable land and hardworking farmers, timely supply of seeds and fertilizers, regular technical backup by ASE, efficient seed collection and payment to farmers, strong government support, and extensive training of farmers and development agents and experts. Finally, this year's accomplishment is highly encouraging and has paved the way for extended improvement in seed production in the region which could benefit both the region and the country at large.

Acknowledgements

ASE would like to thank the Bako National Maize Research Project's research staff for their extended support throughout our hybrid maize seed multiplication program.

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Maize Seed Production and Distribution: The Experience of South Seed Enterprise

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Introduction

Agriculture is the major economic activity in the Southern Nations Nationalities and Peoples Regional State (SNNPRS) of Ethiopia. Several farming systems are practiced in the region within various agro-ecological zones. Small-scale mixed farming (crop and livestock), large scale commercial farming and pastoral farming are prevalent. The most important crops grown in the region are maize, wheat, *tef*, barley, sorghum, coffee and enset, of which maize cultivation is estimated to cover more than 285,279 ha of the farming land annually (AR-SNNPRS-BoA, 2010; CSA, 2010).

Despite the rapidly growing population pressure and increased demand for food and feed in the region, the performance of the agricultural sector has lagged behind expectations. The most important constraints are unavailability of improved varieties, limited access and untimely supply of seed and other agricultural inputs, and limited use of improved agricultural practices.

The use of improved seeds in the region is at very low levels. In 2010, improved seed of maize used in the region was not more than 2,400 t, which was less than the demand. To alleviate the problem of seed shortage the regional government established the South Seed Enterprise (SSE) in 2010. This paper discusses the achievements and future direction of the SSE.

Table 1. Demand and supply of maize over the past four years.

Year	Demand (t)	Supply (t)	Difference (%)
2006/07	3,229.3	1,409.2	43.5
2007/08	3,250.5	1,224.6	37.6
2008/09	4,841.9	1,871.5	38.6
2009/10	5,697.8	2,423.1	42.5
Average	4,254.9	1,732.1	41.0

Seed Production

In the past years, less than 50% of the seed demand in the SNNPRS was met annually (Table 1). The SSE has been established to fill this gap. This year (2010/11) SSE produced more than 4,000 t of seeds of different crops. Seeds of the major crops produced included maize, wheat, *tef*, barley and haricot bean. This indicates that SSE became one of the seed producers and suppliers in the region (Tables 2 and 3). The enterprise produces seed on private farms, state farms, small scale farmers' fields and its own farms.

Hybrid maize is the major seed produced by the enterprise (Tables 2 and 3). To produce high standard quality seed, the enterprise established a criteria to select the potential areas and the farmers. The criteria used to select the area and growers in 2010 were 1) favorable agro-ecology for selected crops, 2) experience in seed production, 3) high demand for seed/technology, 4) accessibility to transportation, and 5) availability of storage facility and labor. Additional criteria such as possession of a minimum of 0.5 ha land, willingness to produce seed and use of recommended practices, and willingness to collaborate with development agents, who supervise the day to day activities, were also considered.

Table 2. Maize seed produced by South Seed Enterprise in 2010/11 in Southern Ethiopia.

	Area (ha)			Yield (t)	
Variety	Planned	achieved	Achieved (%)	Planned	Achieved
BH660	930	861	93	372	1,433
BH540	495	465	94	743	508
BH140	490	673	137	184	803
BH543[†]	75	75	100	263	0
Total	1,990	2,074	104	6,564	2,744

Source: SSE Report, 2010/11.
[†]Failed to germinate due to moisture problem at planting.

Table 3. Maize seed sold (t) from December, 2010 to April, 2011.

Variety	December	January	February	March	April	Total	Price (birr t^{-1})
BH140	7.5	215.7	372.8	110.1	38.2	744.4	15,000
BH540	0.0	100.1	161.1	100.9	17.1	477.0	15,000
BH660	20.6	113.9	114.6	336.8	128.3	714.4	13,290
Total	28.1	429.7	648.6	645.6	183.7	1,935.9	

Source: SSE Report, 2010/11.

In addition to working with small scale farmers, 15 contractual private and state farms participated in maize seed production in 2010. In addition to the criteria used to select small scale farmers an investment license, willingness to collaborate with SSE and presence of agricultural experts were considered as additional criteria for this group of seed growers.

In 2010/11 the enterprise planned to produce maize seed on 1,990 ha of land and achieved 2,074 ha (Table 2). It is an encouraging result for an infant enterprise having only one year's experience in seed production. However, the yield obtained was very low. The main reasons were excessive rainfall in some areas, diseases (grey leaf spot, bacterial ear/cob rot), late sowing, poor agronomic practices on some farms, poor germination of parental materials (like SC22) and dependence on rain-fed seed production.

Seed Marketing

Following the standard procedures of seed production and processing, the final product was made available to farmers in appropriate labeled packages specifying the necessary information about the seed. The Bureau of Agriculture (BoA) controlled the seed marketing processes to fairly distribute the seed to all zones and districts in the region. Thus, based on the demand from the zones and special *woredas*, the BoA allocated the appropriate quantities of seeds of different varieties. Then, distribution to individual farmers was carried out through farmers' cooperative unions. Selling price was decided by the executive board of the seed enterprise considering the direct and indirect costs of seed production and processing (Table 3).

Future Direction

SSE is an infant seed enterprise. To be competent, the enterprise should give due emphasis on capacity building. Additionally, the enterprise with its limited capacity will try to fulfill the seed demand of the region by including more maize varieties (hybrids and open-pollinated varieties) suitable for different agro-ecologies of the region. The establishment of its own seed farm and production of its basic seed requirements will help to meet the target of fulfilling the seed demand of the region in particular and the country in general.

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The Role of Private Commercial Seed Producers in the Maize Industry

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Introduction

The complex interaction of fast population growth, continuously degrading natural resources and limitations in technical and technological inputs has made food security a formidable challenge in Ethiopia. The overwhelming majority of farmers in the country rely on their traditional mode of production and crop landraces. This scenario is in agreement with the general trend in Africa, where it is estimated that more than half the maize area is still planted to traditional unimproved low-yielding varieties (MacRobert, 2009). In Ethiopia in the 2006/07 production year, for instance, less than 4% of the agriculturally cropped land to cereals was covered by improved crop varieties. The situation with pulses, oilseeds, vegetables and root crops was even more dismal. Domestic cereal production shortfalls in the country are commonly compensated for by either importations and/or donations to secure the food situation in the country (Mkumbwa, 2010).

The Ethiopian Agricultural Growth Program identified availability of quality seed as a major challenge. The formal seed sector in the country is served by the dominant public enterprises; Pioneer Hi-bred-Ethiopia, local producers/companies, and community development organizations such as farm co-operatives and unions. In the public domain, the Ethiopian Seed Enterprise has stayed in the business for quite some time and is now being joined by newly emerging regional entities like the Oromia, Amhara and South Seed Enterprises.

The domestic private sector, which is also emerging, is yet to show its relevance in the whole picture of the developing seed sector in the country. Though arguments arise over the right balance between the role of the public and the private sector, some renowned authorities strongly indicate that the private sector should be encouraged to play a greater role in disseminating improved maize varieties in the developing world for a more sustained sector development (Morris, 1998). What does the situation look like in Ethiopia? This paper attempts to assess the role each part currently plays in making improved seeds available to farmers in the country by taking maize as an example. The paper also highlights a few drawbacks of the private sector and draws some conclusions/ recommendations to ameliorate these constraints if this sector is to play the expected role.

Trends in Cereal Crop Production, Consumption and Importation

Cereals comprise the major crops in Ethiopia, though pulses, oilseeds and horticultural crops are also produced. One would expect that through an ever-increasing growth in land area under cereals the growing food needs caused by increasing population could be met. Nevertheless, the long-term trend indicates that land cropped to cereals has dropped from a little over 6 million hectares in 1961–70 to about 5 million in 1981–90 and picked up to over 6 million again over the period 1991–2000. Total production and productivity, however, consistently grew over the same period with inconsistent average growth rates (Table 1).

Maize, wheat and sorghum account for over 95% of the total annual cereal consumption in Ethiopia over the past 45 years (Table 2). Lack of data excluded *tef* and barley which are more important in the Ethiopian dish than millet and rice. Taking 1961–1970 as a base, consumption patterns increased over the period by 14.4, 10.2, 8.0, 7.5 and 30.8 fold for maize, wheat,

Table 1. Cereal crop area harvested, grain yield and annual production over 50 years in Ethiopia.

	Average production area		Yield		Production	
Year	Millions of hectares	Annual growth rate (%)	t ha^{-1}	Average growth rate (%)	Millions of tons	Growth rate (%)
1961–1970	6.3	2.7	0.7	0.8	4.6	2.2
1971–1980	5.1	3.3	1.0	6.1	4.8	1.9
1981–1990	4.9	–0.5	1.2	1.3	5.6	1.4
1991–2000	6.1	7.1	1.2	–0.9	7.1	6.7
2001–2007	8.5	3.0	1.3	3.5	11.3	5.1

Adapted from Mkumbwa, 2010.

sorghum, millet and rice, respectively. The importance of rice, a crop not among the popular traditional dishes, has been increasing substantially over the considered time span.

The daily energy contribution of maize, wheat, sorghum, millet and rice has been indicated in Table 3. Total calories (kcal) of cereal crop intake has been increasing constantly with a slight rift over the period 1971–1980, which appeared to have been caused by a drop in the intake of wheat and rice. The contribution of maize, wheat, and rice jumped from 28.6 to 40.6, 31.0 to 33.0 and 0.1 to 0.5%, respectively from 1961–1970 to 2001–2005. Over a similar period, sorghum's and millet's contributions dropped from 34.8 to 21.5 and 5.5 to 3.5%, respectively.

Close scrutiny of cereal food imports into the country over a recent 45 year timeframe has been indicated in Table 4. Food imports steadily grew on average from 28,591 t over 1961–1970 to 910,905 t over 2001–2005. Wheat on average accounted for 95% of the imports in the considered period and maize and sorghum have also played a role though at considerably lower levels.

Over a relatively similar period, the country received 33.4 million t of cereal food aid (Table 5) to bridge the food deficit gap in complementation to the importation efforts. If efforts are more coordinated to tap the huge existing potential for increasing cereal production and productivity, Ethiopia could easily be turned into a food self-sufficient nation. There are sufficient conditions for optimism to achieve this target with the

Table 5. Cereal food aid donated to Ethiopia from 1970 to 2006.

Year	Amount (t)
1970–1979	110,672
1980–1989	9,789,888
1990–1999	13,105,771
2000–2006	10,448,569
Total	33,454,900

Table 2. Average national cereal food consumption ($t\ yr^{-1}$) in Ethiopia by crop over the past 45 years.

Year	Maize	Wheat	Sorghum	Millet	Rice
1961–1970	523,246	627,888	653,166	113,143	2,972
1971–1980	832,251	676,893	730,956	148,073	1,689
1981–1990	1,264,388	1,116,524	1,046,103	139,705	21,163
1991–2000	2,160,325	1,487,634	1,172,916	182,373	20,453
2001–2005	2,776,255	2,475,725	1,641,860	260,744	45,346
Total	7,556,465	6,387,664	5,245,001	844,038	91,623
% Contribution	37.5	31.7	26.1	4.2	0.5

Adapted from Mkumbwa, 2010.

Table 3. Average cereal food consumption/supply ($Kcal^{-1}\ capita^{-1}\ yr^{-1}$) in Ethiopia over the past 45 years.

Year	Maize	Wheat	Sorghum	Millet	Rice	Total
1961–1970	178.0	192.6	216.5	34.1	0.7	621.9
1971–1980	200.0	161.9	184.7	34.3	0.3	581.2
1981–1990	256.6	202.5	207.1	25.6	3.0	694.8
1991–2000	328.2	214.0	161.9	24.8	2.2	731.1
2001–2005	349.8	292.3	184.9	29.7	3.9	860.7

Adapted from Mkumbwa, 2010.

Table 4. Average cereal food imports (t) to Ethiopia over the past 45 years.

		% Contribution					
Year	Amount	Maize	Wheat	Sorghum	Millet	Rice	Total
1961–1970	28,591	2.3	97.7	–	–	–	100
1971–1980	140,970	1.9	97.4	0.5	0.2	–	100
1981–1990	532,054	2.4	94.8	2.6	0.2	–	100
1991–2000	495,833	4.3	86.6	9.1	–	–	100
2001–2005	910,905	2.7	96	1.1	–	0.2	100

Adapted from Mkumbwa, 2010.

current national drive for agricultural transformation. Partnership between the public and the private sector to avail the much-required agricultural inputs (e.g., improved seed – both inadequate quantity and quality) should be a major focus.

Use of Improved Maize Varieties and the Contribution of the Private Seed Sector in Ethiopia

The Ethiopian seed industry is predominantly served by the informal seed source contributing about 90% the annual seed supply. This is above the 66–85% estimates for resource-poor sub-Saharan African farmers (Monyo *et al.,* 2004; Tripp, 2001). Based on Ministry of Agriculture and Rural Development (MoARD; Unpublished team assessment report of 2007/08), the total demand for improved maize varieties in 2007/08 was 21,091 t (Table 6). Well popularized hybrids, BH660 (38%) and BH540 (31%), accounted for bigger large proportion of this demand while other improved varieties had much lower shares. The national production plan for improved maize seeds for the same year amounted to only 12,090.9 t (Table 7). This production target meets 57.3% of the total demand in that year alone and farmers will have been forced to make up for the gap by reverting to planting unimproved varieties. Undoubtedly, this shift will have substantial consequences on the national grain production.

Though plans for improved maize seed production for the year 2007/08 fell short of the national demand, it was nevertheless an increase of 60% over the previous year's supply that amounted to 7,553.6 t (Table 8). Region-wise, Amhara, Oromia and the Southern Nations, Nationalities, and People's Region (SNNP) virtually consumed all improved seeds produced in 2006/07 with the former two accounting for about 82% of the total consumption. Demand for BH660 far outstripped that of the rest of the varieties that year as well.

Table 6. National seed demand for improved maize varieties in 2007/08.

Variety	Total demand (t)	% of total	Rank
BH660	7,898.8	37.5	1
BH140	976.4	4.6	4
BH540	6,620.2	31.4	2
BH670	405.0	1.9	9
BH543	30.6	0.1	13
BHQP542	422.1	2.0	8
BH541	52.8	0.3	12
30HB83	627.6	3.0	7
PHB3253	2,244.4	10.6	3
A511	646.2	3.1	6
Katumani	812.7	3.9	5
Toga(ESE203)	236.0	1.1	10
Melkasa1	82.0	0.4	11
30V53	30.0	0.1	13
Total	21,091.3	100.0	

Adapted from MoARD data, unpublished report, 2007/08.

Table 7. National plan to supply improved maize varieties in 2007/08 by variety.

Variety	Planned to supply (t)	% of Demand	Remarks
BH660	2,859.5	36	
BH140	1,518.2	156	Produced surplus to demand
BH540	2,675.9	40	
PHB3253	1,235.0	55	
Katumani	806.3	99	
BH670	331.2	82	
BH543	135.0	–	Produced without demand
BHQP542	121.5	397	Produced far above demand
BH541	–	–	
30HB3	665.0	106	Produced surplus to demand
A511	946.0	146	Produced surplus to demand
Toga(ESE203)	67.5	29	
Melkasa1	150.0	183	Produced surplus to demand
30V53	95.0	316	Produced far above demand
Arganne	105.0	–	Produced without demand
Total	12,090.9		

Adapted from MoARD data, unpublished report, 2007/08.

Table 8. Improved maize seed (t) delivered in 2006–2007 to regions by variety.

	Variety										
Region	BH660	BH140	BH540	BH670	A511	Katumani	BHQP542	Toga (ESE203)	Gibe1	Melkasa1	Total
Oromia	2,1710	2,564	1,787	–	1,206	1,308	65	50	–	–	2,869
Amhara	20,233	–	7,412	540	2,596	1,498	482	241	–	–	3,300
S.N.N.P	7,497	–	2,558	–	–	150	1,043	50	–	–	1,130
Tigray	–	–	30	–	–	59	20	20	–	40	17
Harari	–	10	–	–	25	25	10	–	–	–	7
Somali	–	100	–	–	–	400	–	–	–	450	95
Afar	–	728	100	–	100	–	–	–	–	30	96
B/Gumuz	10	150	120	–	–	–	50	–	70	–	40
Total	4,945	355	1,201	54	393	344	167	36	7	52	7,554
%	65.5	4.7	15.8	0.7	5.2	4.6	2.2	0.5	0.1	0.7	100

Adapted from MoARD data, unpublished report, 2007/08.

Commercial seed production in the Ethiopian seed industry is largely dominated by public enterprise (Bishaw *et al*., 2008). Of the total improved maize produced in the country in 2006/07, public enterprises accounted for 69%, whereas the private seed sector aggregated a share of about 28% (Table 9). The Ethiopian Seed Enterprise had the greater proportion (95%) of the total public seed production in the year under review. Pioneer Hi-bred Ethiopia dominated the private sector with a share of about 82% of the sub-total for this category of producers. Although, total maize seed production has been increasing in recent years, the share of private seed companies has remained unchanged (Mosisa *et al.,* 2011).

The private commercial seed sector is an emerging component in the Ethiopian seed industry. About ten years ago Pioneer Hi-bred and Anno Agro-industry were the only two private seed producers on the scene while today, more than 26 small and medium seed producers are operating in the country. The Ethiopian seed sector is now diversified and served by more public enterprises, community institutions and private commercial producers catering for and complementing each other to improve the supply of improved seeds in the country.

Conclusions and Recommendations

Agriculture remains the main economic cornerstone for Ethiopia with its leading role being maintained for quite some time and well into the foreseeable future. Past efforts to improve production and productivity in the sector had seriously been frustrated by shortages and failure of adoption of technological inputs. As a consequence of the inability to produce sufficient to feed the nation, the country is commonly forced to depend heavily on cereal food imports and aid to compensate for the food deficits. A key factor among the production enhancing inputs, which has largely been in short supply in the country over several years in the past and still remains a major challenge, is improved crop seeds. The responsibility of making improved seeds of the various crop varieties available to farmers has solely been shouldered by the Ethiopian Seed Enterprise for a long period.

Critical shortage of improved seed has opened up a window of opportunity for the emergence and growth of additional public regional seed enterprises as well as small and medium-scale private seed producers and commercial seed companies. As a young emerging industry, the private seed sector is stifled by quite a number of constraints and its market share is currently substantially low. More efforts need to be made to improve the role of the private commercial seed sector.

National effort is, of course, underway to bring more public enterprises and community-based seed production systems onto the scene and this is a commendable move as a short-term intervention. Nevertheless, a long-term solution to sustained growth and development in the seed industry is to encourage the private sector to play a greater role in

Table 9. Improved maize seed (t) delivered by public and private producers in 2006–2007 by variety.

Source	Variety									Total
	BH660	BH140	BH540	A511	Katumani	BHQP542	Toga	Gibe1	Melkasa1	
ESE	3,604.7	491.6	931.1	392.7	344.0	167.2	36.1	54.0	52.0	6,080.2
Awassa Farm	95.9		125.6							221.5
Coffee Develop	37.1									37.1
Bako Res.	94.2									94.2
Sub-total (69.2%)										6,433.0
Meki-Batu (2.7%)										250.0
Pioneer										2,124.8††
Chombe Farm		66.0†								66.0
Anno Farm	134.7									134.7
Gadisa Farm	11.8									11.8
Hadiya Farm	29.7		49.5							79.2
Green Wood	143.4									143.4
Nonno Farm	53.8									53.8
Sub-total (28.1%)										2,613.6
Total (100%)										9,296.6

†7.4 t not sold and remained with the producer, ††Pioneer varieties were 30HB3, PHB3253, and 30G19.

the seed business with the public focusing more on regulatory and certification aspects. A strong public/private partnership is crucially important at this early development stage of the seed industry. The public enterprises may have to maintain the bigger seed production share for some time with a vision of gradually minimizing their roles and being replaced by a growing private sector.

The private sector should build its capacity by fostering a strong linkage with national as well as international agricultural research entities to minimize its current total reliance on public research as a source of early generation seeds. There are only about two local private seed producers that produce their basic seed and do not depend on the national research centers at present. Strengthening its institution, the Ethiopian Seed Growers Association is a key element for the sector's growth and development. Currently, several seed producers are not members of this association. The association should prove its relevance to attract more membership from prospective candidates.

Challenges to the Development of the Private Commercial Seed Sector

The private commercial seed sector in the country is beset with a number of drawbacks among which, the following are just a few:

- Heavy dependence on rain-fed production
- Low farm productivity
- Fluctuating grain prices
- Unethical acts of some unscrupulous producers/traders
- Under-developed regulatory system
- Lack of knowledge on actual seed demands to plan production
- Poor seed quality
- Limited distribution channels
- Limited product focus, e.g., on hybrid maize
- Low demand for improved seeds including other crops than hybrid maize and wheat
- Absence of market promotion strategies
- Weak affiliation of potential members to the Ethiopian Seed Growers and Traders Association
- Inadequate working capital
- Poor entrepreneurship
- Weak physical capacity

The Way Forward

The private seed sector needs to take the following critical steps to increase its market share:

- Strengthen its association to engage in a more positive policy dialogue to benefit the welfare of its members in particular and that of the national seed sector in general
- Make relentless efforts to improve its capacity (technical, physical and capital) to produce more quality seeds at an individual farm/company level
- Build and utilize a strong network of information (local, national, regional and international)
- Contribute to the fight against unethical acts by unscrupulous seed producers/traders
- Foster a stronger partnership among public seed enterprises, community seed producing entities, private producers, and commercial companies to change competition challenges to opportunities
- Establish strong linkages with national and international agricultural research and educational bodies
- Strategize production and marketing targets in light of the ensuing market competitions
- Engage in market promotion activities to enhance own production items
- Build capacity to engage in the production and marketing of early generation seed where technically and physically feasible

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The Use of Pioneer Maize Hybrid Seeds and its Impact on Small Scale Farmers of Ethiopia

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Introduction

The exact origin of maize is lost in antiquity. Some think that maize originated in the highlands of Peru, Bolivia and Ecuador, but most scientists now believe that maize crop was originated in South Mexico and Central America. Thus, maize is considered to be native to the Americas. The oldest archeological maize, carbon dated at about 5000 B.C. was found in the valley of Tehuacan in Mexico. Now, maize is one of world's three most important cereal crops (rice, maize and wheat). It is currently grown in all continents except Antarctica. Today, more than 300 million Africans rely on maize as their main food source. Maize is used as food for human consumption, as feed for livestock and currently as fuel for vehicles. The crop is rapidly spreading all over the globe because it is relatively easy to cultivate and most productive where rainfall and irrigation is adequate (Hoeft *et al.,* 2000).

Maize was introduced to Ethiopia in between the 1600s and 1700s (Haffnagel, 1961). Even though the introduction of maize to Ethiopia is a recent phenomenon as compared to the indigenous cereal crops such as *tef*, wheat, sorghum, barley etc., today it is one of the most important food crops of the country. The crop is predominantly grown in the southern, western, central and eastern parts of the country. Due to its importance primarily as food, maize is considered as one of the priority crops in an effort to meet the food demand of the country's increasing population. In 2010, the productivity of maize was 2.3 t ha^{-1} (CSA, 2010), which is low in light of the potential productivity of the crop under good management conditions; 6–12 t ha^{-1}. Such a wide gap was created by various production constraints such as low inputs, decline in soil fertility, pest and diseases and overall environmental degradation. However, the major factor that attributes to low productivity of maize is lack of quality seeds.

On the other hand, due to rapid population increase particularly in the highland areas, we are essentially challenged to produce more grain for food on smaller plots of land cultivated to feed the growing population. Under such pressing circumstances it is more important than ever to achieve the maximum possible yield on every hectare of land under cultivation. This is mainly possible by using agricultural technologies generated by public research and other business organizations. One of the most important and key technologies that can increase maize yield is the use of hybrid seeds, as it all starts with seed. Norman Borlaug, the founder of the Green Revolution started with quality seeds to avert famine and saved hundreds of millions of lives, lifting countries like Mexico and India out of hunger and poverty.

When the need of hybrid seeds as an important tool to increase productivity was realized, there were no other private companies in the country other than Pioneer Hi-Bred Seeds Ethiopia. The Company was established in Ethiopia as a joint venture between Ethiopian Seed Enterprise and Pioneer Overseas Corporation (POC) in 1990. The principal business objective was the production of hybrid seeds for the state farms. With a change of government in the country, the two entities were separated due to conflict of interest and POC was reorganized as Pioneer Hi-Bred Seeds Ethiopia PLC in 1996 with the same objective of producing and delivering hybrid seeds to farmers.

Objections Raised to Planting Maize Hybrid Seeds

In the beginning, there were serious objections to planting maize hybrid seeds by small scale farmers on the following grounds.

1. Hybrids will create dependency and vulnerability: This argument says that farmers must buy new seed each year to avoid a significant yield drop from using saved seeds and only depend on seed growers.
2. Hybrids will cause deterioration to the land races: If grown close to landraces some pollen from hybrid maize could contaminate the land race seed source for the following season and disrupt the maturity and disease character. However, the hybrid could pass on genes that help increase the yield of the landrace.
3. Seed supply and availability not adequate: This is a valid critique. If farmers are promised the benefit of hybrids and the seed is delivered in small quantities or fails to meet demands, the benefit may not be realized and farmers may lose interest in investing in seed.
4. Hybrid seed costs are too high: This is critical where farmers typically have little or no cash at planting. Hybrid seed costs more to produce than open-pollinated varieties (OPVs) because of the necessity

of maintaining different inbred lines and also requires additional labor for detasseling to produce the hybrid seeds.

5. Lack of adaptation due to improper positioning: If seed producers do not conduct adequate field testing, some hybrids may be marketed in areas where they are not adapted and end up with poor performance. As a result farmers suffer the consequence of yield loss.
6. Fertilizers required for hybrids are too high: This belief seems to be incorrect because when hybrids receive adequate fertilizers they yield high, but under low-yielding environments, their stress tolerance gives them better yield than OPVs.
7. Poor storability: This is characteristic to some hybrids that are floury types and do not resist storage insect attack.
8. Hybrids yield too much and drive down grain price: This has occurred as the infrastructure of the country is inadequate to handle excess grain and storage facilities were not well developed.
9. The genetic uniformity of hybrids makes them susceptible to disease: When the environmental conditions become favorable for the diseases to develop in certain areas, a vast area of maize could be affected due to similar genetic susceptibility.
10. Farmers might recycle hybrids and use F_2 and subsequent generations as seeds and suffer severe yield loss: In cases where there is inadequate supply of seed, farmers might be forced to use F_2 grain as seed.

Progress of Pioneer Hi-Bred Seeds Ethiopia in Production and Distribution of Maize Hybrid Seed

Hybrid seed development, testing, registering, producing, and commercialization was difficult in light of the objections mentioned above. It also requires a great deal of time, effort and money, as activities involved are performed by high level of professionalism, skills and technical capabilities. Pioneer Hi-Bred Seeds Ethiopia, subsidiary of Pioneer Hi-Bred International based in De Moines, Iowa USA, with the creation of an enabling policy environment by the Ethiopian government and a convincing performance of locally and Pioneer developed hybrids demonstrated on small scale farmers' fields by Sasakawa Global 2000 (SG2000) (Takele, 2002), the company broke the deadlocks and became the pioneer private seed company in producing and marketing maize hybrid seeds in Ethiopia. Addressing these challenges, however, involved situations that were not soft or smooth in their forward movement.

Furthermore, agronomists and sales people from the company identified influential individuals in each community to be its partners and strongly explained the benefits of using hybrid seeds by conducting demonstration plots on their farms side-by-side with OPVs and landraces, putting signage of plots, organizing field days and demonstrating values. Sample seeds are also provided to innovative and prospective farmers followed by delivery of agronomic advice, thereby demonstrating good management practices of hybrid seeds so that they may obtain high yields from sample seeds and may be convinced by what Pioneer is saying and showing. Consequently, Pioneer Hi-Bred Seeds Ethiopia PLC successfully convinced innovative farmers and started distributing hybrid seeds to small scale farmers in 1996.

To comply with the regulatory approval of the government, all Pioneer commercial hybrids are tested and officially released and registered by the Ministry of Agriculture (MoA) regulatory department. After official release and registration, Pioneer produces seeds on grower's farms, both public and private, processes, conducts quality tests by the authorized regulatory body of MoA and then distributes seeds to customers based on a pre-assessed demand to meet the requirement of the season. Pioneer has the seed industry's highest quality control standard in Austria, where seeds are sent for genetic quality testing before delivery, assuring farmers that they obtain the highest quality seed for planting. To continually achieve the delivery of high quality and pure seeds, Pioneer invests significant time, resource and technology on seed production. The delivery of high quality seeds that are high yielding and agronomically superior helped Pioneer to accomplish the highest competitive advantage in retaining customers and converting prospects into good customers, consequently increasing its market share in the country.

Since the start of Pioneer Hi-Bred Seeds Ethiopia hybrid seeds distribution by volume is steadily growing (Table 1; Fig. 1). This is primarily due to the fact that the company is operating in consistence with its Long Look Philosophy, "We give helpful management suggestions to our customers to assist them in making the greatest possible profit from our products" which is at the core of its focus. Following this guiding principle we continually and properly position our products in the right environment and execute effective field demonstrations and field support to customers by visiting and walking into their farms so that they feel comfortable using Pioneer hybrids (genetics) in order to increase their productivity per unit area and income while pricing for value.

Table 1. Current commercial hybrids and sales status, 2010.

Hybrid	Days to maturity	Sales status (%)	Strength
3253	133	48.0	stable, fit for green cob
30G19	138	29.3	yield, grain quality
30D79	137	1.7	husk cover, leaf diseases
P2859W	128	under promotion	early, leaf diseases

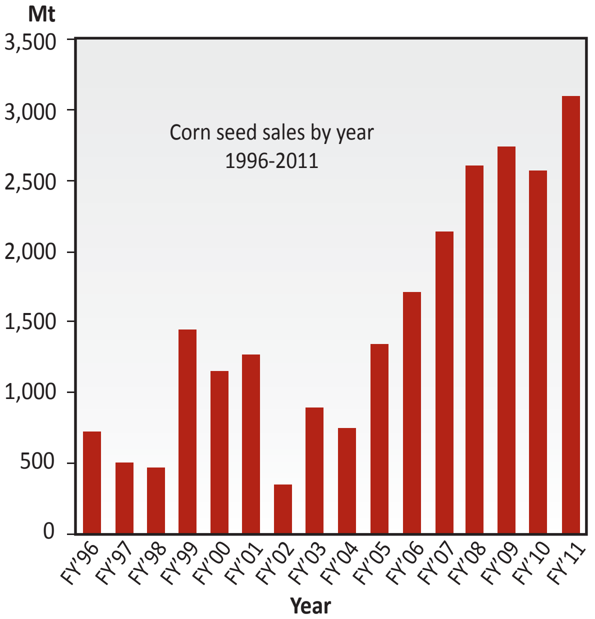

Figure 1. Pioneer seed sales from 1996 to 2011 in Ethiopia.

FY= Fiscal year

Impacts of Pioneer Hybrid Seeds

The introduction and commercialization of maize hybrid seeds has positively impacted the livelihood of small scale farmers and other stakeholders as follows:

1. Small scale farmers increased their capacity and their management skills to grow hybrids thereby producing adequate food supply for their family. By selling grain in excess of their home consumption, their financial position is strengthened enabling them to pay for medication and sending all their school age children to schools. Most of the farmers growing Pioneer seeds changed their thatched houses to corrugated iron sheets.
2. Private commercial farmers have increased their grain production capacity by growing Pioneer seeds and purchased more farm machinery such as tractors, combine harvesters, planters, irrigation facilities etc., increased the size of their farms, and improved their storage capacity with the additional income they generate by planting Pioneer seeds.
3. The country has also benefited from the introduction of hybrid seed technology by enhancing the food self-sufficiency program and poverty reduction effort of the government. The investment in hybrid seeds and grain production provide employment opportunities for many citizens. Pioneer being in the fore front of hybrid seed production and marketing, the experience gained by the company, both challenges and good lessons learned, is very important and useful for the development and growth of the seed industry in the country. Pioneer has played an important role in enhancing a culture of seed technology acceptance in the country. Moreover, the company contributed to the proliferation of private commercial farmers growing grains and seeds contributing to food self-sufficiency and poverty reduction effort of the government. The country has also benefitted from the community investment outreach program of Pioneer Hi-Bred International since 2005.
4. As Pioneer is producing and delivering high quality seeds to farmers that ultimately increase their productivity and income thereby improving the quality of their livelihoods, the company has gained a good image and reputation, created goodwill and credibility as well as a high level of trust and acceptance by farmers. Pioneer becomes an important player in the seed industry game by making a difference to productivity gains.

Benefit of PHB3253 to farmers

While seed selling is critical and often described as the real work, Pioneer Hi-Bred Seed Ethiopia sees results in other ways. Pioneer is helping farmers in rural areas and making a difference in their livelihoods. All small scale farmers who grow Pioneer seeds increased their income and improved their livelihood by selling dry grain harvested from their farm plots. But small scale farmers in South Ethiopia, particularly farmers of the Damote Galle and Badowacha districts of Wolaita and Hadiya Zones, respectively, grow maize to sell as green cobs to generate better income.

They harvest and sell green cobs for three different reasons:

1. The area is densely populated and individual land holdings are very limited (<0.5 ha). To meet the food demand of the growing population of their localities, farmers need to harvest twice or more in a year. This is only possible when they grow maize varieties that fit into the green cob cropping pattern allowing them to plant the next crop in the same season.
2. They can generate a better income when they harvest green cobs than harvesting dry grain that takes a longer time in the field, hindering the opportunity of growing a second crop.
3. Such a cropping system permits crop rotation, thereby restoring soil fertility and increasing productivity and delivers better benefits to small scale farmer in the districts.

Assessing the market opportunity in the district, Pioneer agronomists realized that Pioneer brand PHB3253 uniquely fits into the cropping system and delivers better benefits to small scale farmers of these districts. The hybrid is correctly positioned in the green cob market segment and accompanied by well-organized field days that explicitly explain the benefit of the product to targeted key farmers that are innovative and highly accepted by the community.

Through one-on-one communication, farmers' meetings for green cob harvest, continuous visits and discussions with key farmers regarding the performance and merit of the hybrid when harvested as green cob, farmers are convinced and excited about the vigor, grain quality (taste), and fitness (fat cob) into the green cob cropping system of the area the fact that it fetches a good price in the market places of big cities including Addis Ababa, Hawassa, Adama, Shashemane, etc.

The superior performance of the hybrid accompanied by high quality agronomy services of Pioneer professional agronomists convinced and influenced the resource poor farmers to grow seeds of PHB3253 as green cobs and enabled the business unit to capture more than 90% market share of the districts. By growing Pioneer hybrid and selling green cobs, the quality of life of most small scale farmers has improved significantly. Though, small scale farmers are the first in a line to get benefits from green cob production and marketing by generating high income, local brokers, traders, transporters, who lesalers, street venders, who are the largest retail segments, city dwellers and seed suppliers are all beneficiaries of the green cob supply chain.

Ato Debebe Ayele, an innovative farmer in Baowacha district of Hadiya Zone, near Shone town, who grew Pioneer seeds for more than ten years, changed his life and the lives of his 2 wives, 16 children, and 6 adopted orphans. Let me quote what he said when he was visited and interviewed by a Wall Street journalist from the USA,

"Our population is increasing at an unprecedented rate and useable land is limited in this area. My concern was how to feed my large family when things drastically changed with the introduction of Pioneer hybrid maize seed to our district which I planted as the first person in the district since I realized that seed is the vehicle of change. From the day I started growing Pioneer hybrid maize I am harvesting twice a year from the same plot of land. As a result I adequately feed my family the whole year round and have surplus grain for the market. My thatched house was improved with corrugated iron sheets and I am sending all my children to school with adequate supplies. Five of my children attend private college. I bought television and radio for entertainment and follow agricultural news and watch the trend of grain price. I bought mobile phone for better communication. I bought dairy cows and earn reasonable income from supplying milk to the community. There is a lot of change in my day-to-day standard of living; we are well dressed, and healthy looking. As a result, my social status has improved. I consistently advise my friends, neighbors and all farmers in my community to grow good quality seeds and improve their livelihoods and as a result many farmers in my community and even in other districts grow Pioneer seeds and improved their livelihoods like myself".

Major Challenges

1. Management issue: Hybrids are potentially high yielders when accompanied by good management practices. Although most farmers have satisfactorily improved the level of their hybrid farm management practices and are able to exploit genetic yield potentials of hybrids as they have been growing for the last fifteen years plus, still there are farmers who are not managing the hybrids up to expectation. Consequently, they fail to obtain expected yields from genetically high yielding hybrid seeds and attribute low yields to poor quality seeds.
2. Recycling of hybrid seeds: Due to a lack of information, cash, and/or adequate availability some farmers recycle hybrid seeds which results in low yields as the second and subsequent generations of hybrid seeds do not have the same genetic attributes of yield or any other traits as the first generation due to segregation.
3. Value appreciation: Hybrid seeds are usually priced for value. Some farmers still do not realize added value obtained from hybrids. Without realizing benefits captured from added value of hybrids they can mistakenly conclude that Pioneer seeds are expensive, when the reality is untrue.
4. Uncertainty of rainfall: Maize crops deliver high yield under ideal moisture and temperature conditions. But due to the uncertainty of rainfall and other weather factors yield of maize can be drastically reduced or sometimes end up in total harvest loss. Late onset and shortage of rain in eastern, southern, and Rift Valley areas of the country sometimes affect maize production. Excess rain in western and north western parts of the country cause water logging on black soils, hail damage, lodging, resulting in severe yield and quality loss.
5. Diseases: *tarcicum* leaf blight, common leaf rust, maize streak virus and grey leaf spot are the major leaf diseases that are threatening hybrid maize production when the environment favors them.
6. Soil fertility: Most of the farm land soils of Ethiopia are degraded primarily due to lack of soil conservation practices and continuous cultivation without replenishing the soil. As plants grow, they absorb nutrients from the soil. Farmers harvest those nutrients when they harvest crops. If the amount of nutrient removed from the soil is not returned adequately in fertilizer form, the subsequent crop will not get the required quantity of nutrient for its full growth and development and its harvest yield is highly reduced. Moreover, fertilizer use in our country is very low, and is less than 22 kg ha^{-1} as compared to greater than 83 kg ha^{-1} for developing countries. As a result, maize hybrids do not get the required amount of nutrients to express their yield potentials.
7. Failure to supply adequate seeds to meet farmers demand: In some years, there is a shortfall of seed supply and the demand of farmers is not met.
8. Volatility of grain price: Farmers buy inputs only when they get a good price for their produce. Low grain price has prohibited farmers from buying hybrid seeds.
9. Absence of adequate irrigable land to produce quality seed, absence of well-structured distribution channels and unfair competition with subsidized public seed companies are other limiting factors.

Future Efforts

Future efforts required include:

1. Increase hybrid lineup with high emphasis on disease tolerant hybrids
2. Intensively working on proper positioning of upcoming hybrid seeds
3. Continue increasing the hybrid knowledge of our customers through well-coordinated agronomy service activities which differentiate Pioneer from others
4. Working hard in order to bring drought tolerant and nitrogen use efficient hybrids to the marketplace
5. Increase seed production to meet customers' growing seed demands
6. Improve distribution channels by training efficient dealers in major maize growing districts

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Development of Suitable Processes for Some Ethiopian Traditional Foods Using Quality Protein Maize: Emphasis on Enhancement of the Physico-Chemical Properties

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Introduction

Maize constitutes a major food source for the majority of the Ethiopian population, being the second most important cereal crop in area and first in total production in Ethiopia (CSA, 2010). Maize grain is composed of carbohydrate (about 72–77%), protein (8–11%) and fat (3–18%). Nevertheless, maize is deficient in tryptophan and lysine which are essential amino acids for mono-gastric animals like human beings. Therefore, to overcome this problem it is advisable to consume maize together with legumes, oil seeds, animal products, etc. which provide the required amounts of protein and the limited amino acids. Maize supplies at least one-fifth of the total daily calories in Africa, and accounts for 17–60% of the total daily protein supply of individuals in 12 countries as estimated by FAO food balance sheets (FAO, 1992, 1994). The introduction of new quality protein maize (QPM) genotypes can greatly enhance the nutritional status of consumers or improve the efficiency of mono-gastric animals' performance.

In Ethiopia, maize is used in many traditional food products such as *injera* (fermented thin flat bread like honey comb with evenly distributed eyes), *dabo* (traditional bread), *kitta* (unleavened bread), *anebabero* (double layered *injera*), porridge, local alcoholic beverage (*tella* and *katikala*); and serves as a complementary ingredient in composite flour, cookies, etc. Asrat and Lakech (1994) reported that the final product of maize-based recipes on breakfast and snack foods were found to be promising. Efforts have also been made to explore how maize could be widely adapted as a staple in the Ethiopian diet and for the formulation of complementary foods for infants and young children. In this respect a survey was conducted on the traditional use of maize in principal growing regions of Ethiopia and a teaching manual was prepared on traditional maize products, different recipes were also incorporated which could easily be adopted by the consumers (Asrat *et al.*,1998).

Traditional Foods From Maize in Ethiopia

Different traditional food and beverage preparation methods of maize are summarized as follows:

Roasted maize: Green cob is roasted directly on the glowing fire. This method seems very common all over the country and it is consumed seasonally, only when maize is at dough stage.

Toasted maize: Either green or dry maize is toasted on a pan and served as a snack between meals.

Nefro: Green cob or dry whole grain is boiled in a pot until it is soft and then served between meals as a snack. Sometimes salt could be added for a better taste.

Kinche: Split maize is cooked in a pot until it is soft enough and eaten as a breakfast or snack food. Whenever available butter is added to the *kinche* before it is served. Salt could be added just for taste.

Injera: Fermented thin flat bread with evenly distributed eyes like a honeycomb. It is one of the Ethiopian staple foods prepared from cereals (*tef*, sorghum, barley, wheat, maize, millet, etc.). *Injera* is served with different kinds of sauces.

Dabo (bread): Maize flour is made into a thick dough and allowed to ferment for about 4–6 hrs. Then the dough is baked on a clay griddle. Sometimes unfermented dough is also made into bread in some places. Maize flour which is mixed with water and salt is wrapped with enset leaves and boiled in a clay pot for about 30 minutes. The bread which is known as *gafuma* is then served with cooked *kale*.

Kitta: Maize flour is mixed with water and baked, in most cases it is an unfermented product. In some places, however, fermented dough is often made into *kitta*. This is the case of *torosho* which is mainly prepared in some parts of Oromia and southern regions. *Kitta* is sometimes broken into pieces and mixed with butter and chilli powder and eaten as *chechebsa*.

Genfo (stiff porridge): Maize grain is cleaned and milled into fine flour and *genfo* is prepared while mixing the flour in boiling water and it needs to be cooked until it retains the right consistency and flavor; in many places it is consumed as a main dish. The porridge is mostly served with sauce made up of butter and chilli powder. In some cases yogurt, oil seed powder, milk, and milk products could also be added while being consumed.

Kurkufa (porridge): Mixture of maize flour, *kale, moringa/aleko/shiferaw* (green leafy vegetables) and other ingredients.

Fossesie (porridge): Mixture of maize flour, pulses and other ingredients if available meat could also be added. *Fossessie* could be a complete meal and could be consumed alone when enriched with green leafy vegetables. In the preparation of *Fossessie* if fresh haricot beans are not available they are replaced with overnight soaked ones. In the preparation of *Fossessie,* cooked *kale, moringa/aleko/shiferaw* (green leafy vegetables) can also be added to improve its nutritional quality.

Besso (roasted maize flour): Prepared from roasted maize flour, mixed thoroughly with hot water or cow or soya milk (if available). Sugar or salt (for taste) is added and served to any of the age groups. Preferably, QPM *besso* could be prepared from a mixture of QPM and pulses, so that the nutritional quality is improved.

Soup: Prepared from maize, preferably QPM, and mixture of various kinds of vegetables.

Salad: Salad prepared from maize, preferably QPM, and mixture of various kinds of vegetables.

Tella/katikala (traditional alcoholic beverages): Maize is one of the main ingredients of *tella/katikala*. The ingredient used for *katikala* is the same as *tella* but *katikala* involves the distillation process and contains highly unpurified alcohol.

As discussed above, different traditional foods and beverages are made from maize. Though efforts have also been made to prepare user's manual for the preparation of different traditional foods, no information is available for QPM-based traditional food preparation. Since QPM has better protein quality than the conventional maize (Table 1), a different formulation for the preparation of various traditional foods is essential. Therefore, the objective of this paper is to document suitable food processing methods for the preparation of some common traditional foods from QPM and mixtures of QPM and other crops.

Materials and Methods

Sample source

Grain of a QPM variety (BHQP542) was obtained from Bako National Maize Research Project. The conventional maize, other grains, cassava and *bulla* (enset product) were bought from the local market. The grains were cleaned to be free of dust and any other foreign materials.

Food processing

A total of 95 trials were conducted to prepare *injera*, *dabo*, *anebabero*, *kitta* and porridge. Each trial was done in triplicate and finally similar recipes were used to develop standardized methods for preparing and evaluating the end products. Pilot plant trials were conducted to establish process parameters for the small-scale production of maize-based products.

Injera: QPM and other grains were cleaned manually and milled into flour. The flour was mixed with water and *ersho* (starter) and kneaded until the dough was formed. It was then fermented for 24 h and baked into *injera*. A composite of flours of different products were also used (Table 2).

Dabo: QPM and other grains were cleaned manually and milled into flour. The flour was mixed with salt, oil and *ersho* (starter). Water was added and kneaded until stiff dough was formed. This was followed by fermentation and baking. A composite of flours of different products were also used (Table 3).

Anebabero: QPM and other grains were cleaned manually and milled into flour. The flour was mixed with water and *ersho* (starter) and kneaded until the dough is formed. It was then fermented and baked into *anebabero*. A composite of flours of different products were also used (Table 4).

Genfo: QPM and other grains were cleaned manually and milled into flour. The flour was thoroughly mixed in boiling water. A composite of flours of different products were also used (Table 5).

Laboratory work and food analysis

Laboratory investigation was carried out to establish appropriate process methods for these products, which could serve as standard procedures for similar products (AOAC, 1984).

Sensory evaluation

The qualities of the developed products were evaluated by trained panel members who are the staff of the Ethiopian Health and Nutrition Institute (EHNRI). A total of ten panelists were selected to assess the acceptability test of the products. The sensory attributes were appearance, texture, flavor (taste and smell) and overall acceptability. A ranking system—a five point (1–5) scale ranging from poor to excellent—was used, denoting inferior to superior qualities (Watt *et al.,* 1989).

Results and Discussion

Nutrient analysis of QPM, conventional maize and *tef* grains

Nutritional analysis of QPM, conventional maize (Agren and Gibson, 1968) and *tef* are indicated in Table 1. According to the analysis, average contents of calories, moisture, protein, fat, carbohydrate, crude fiber, ash, calcium and iron for QPM were found to be in close agreement with the findings of Agren and Gibson (1968) for conventional maize. However, the QPM protein proved to be higher in nutritional quality than common maize proteins because it contained 30% to 82% more lysine and higher levels of tryptophan (Villegas *et al*., 1980). As a result, the QPM amino acid profile gives a good balance of total essential amino acids. Calcium and iron content seem to be high in *tef*. When maize and *tef* samples are compared, fat is high in maize samples and low in *tef* because maize is among those cereal crops with high fat content. Regarding crude fiber and ash, *tef* comprises a high amount of these nutrients as compared to maize samples.

Sensory evaluation

Unlike conventional maize, QPM was highly preferred by the panel members for its taste and superior baking quality in the production of softer and less fragile *injera* and *dabo*. Similarly, Akalu *et al*. (2001) reported that *injera* and *dabo* prepared from QPM maintained its softer texture and stayed longer than that of the conventional maize. In addition, it was also observed that QPM developed a less sour taste during the fermentation process. This improved the functional properties of QPM by making it more palatable, and may increase the utilization of QPM in the preparation of weaning and complementary foods. Similarly, it was found that porridge prepared from QPM was smoother as compared with the conventional maize. Hence, the agricultural production as well as the utilization of QPM by the general population should be encouraged.

The outcome of the discussion with the panel members was very satisfactory in terms of QPM utilization in traditional food preparations. Many positive points related to the QPM were mentioned by the panel members and constructive responses were indicated to enhance the consumption of QPM. The distinctly favorable comparison of the quality of food products prepared from QPM with that of wheat and/or *tef* should play a major role as a driving force for the adoption of QPM, particularly in areas where maize is used almost exclusively in preparing foods for their daily consumption.

Table 1.Nutrient content of quality protein maize (QPM), conventional maize and *tef* per 100 g.

Nutrient	QPM	Conventional maize	*tef*
Calories	373.8	356.0	363.9
Moisture (%)	10.8	12.4	11.0
Protein (%)	9.9	8.3	9.9
Fat (%)	4.9	4.6	2.6
Carbohydrate (%)	70.7	73.4	70.1
Fibre (%)	2.2	2.2	3.4
Ash (%)	1.6	1.3	2.9
Calcium (mg)	7.2	6.0	138.3
Iron (mg)	3.8	4.2	47.4

Source: Ethiopian Health and Nutrition Institute, 2009, for QPM and Agren and Gibson (1968) for convential maize.

Injera

A total of 25 *injera* trials were formulated using various combinations of composite flours, and of which 18 trials were found to be acceptable by the panel members. The rejections were due to a sticky or crumbly texture, uneven eye distribution and off-flavor. The results of the experiments are summarized in (Table 2). The scores were given out of 5 possible points. The product should score 50% or above to be acceptable by the panel members. As indicated in Table 2, the overall acceptability of *injera* prepared from *tef* was 3.9 while that of QPM and local maize was 3.7 and 2.9, respectively. Mixing 90% of QPM with 10% of rice increased the overall acceptability to the extent of 4.4. Mixing cassava also resulted in improving the overall quality of the products; also the addition of 5% and 10% cassava increased the overall acceptability to 3.8 and 3.9, respectively (Table 2). This is due to the characteristic feature of rice and cassava flour being soft when prepared as *injera*.

When fermentation time exceeds 24 h (100% QPM), especially in warm weather conditions, the product develops a sour and unacceptable flavor. The phytic acid contents in several food grains including maize, rice, millet, sorghum, have been reduced while it is being fermented (Reddy and Salunkhe, 1980; Kebede and Urga, 1995). Fermentation also plays a role in improving protein digestibility and the nutritive values of cereals and legumes. However, it was reported by

Table 2. Case summaries for *injera* (mean score)

Product code	Appearance quality	Texture quality	Flavor quality	Overall acceptance
100% *tef*	3.7	4.3	3.9	3.9
100% QPM	4.3	2.8	3.7	3.7
95% QPM + 5% cassava	4.5	3.7	3.7	3.8
95% QPM + 5% wheat	4.0	3.5	3.7	3.3
50% QPM + 50% *tef*	4.5	4.4	4.0	4.4
90% QPM + 10% cassava	4.9	3.7	3.7	3.9
90% QPM + 10% wheat	3.4	3.0	2.9	3.0
50% QPM, 30% *tef* + 20% sorghum	4.1	4.4	4.1	4.3
85% QPM + 15% cassava	4.3	3.1	3.4	3.1
85% QPM + 15% wheat	2.0	2.0	2.4	2.1
100% local maize	3.8	3.0	2.6	2.9
50% QPM + 50% rice	5.0	4.8	4.9	4.8
80% QPM + 20% rice	4.4	3.6	3.5	4.0
90% QPM + 10% rice	4.9	4.3	4.5	4.4
80% QPM + 20% *tef*	4.4	3.6	2.8	3.2
80% QPM + 20% barley	2.8	2.9	2.6	2.6
80% QPM, 10% wheat + 10% sorghum	3.1	2.9	2.8	2.8
80% QPM, 10% *tef* + 10% sorghum	4.4	3.7	3.3	3.7
Mean	4.0	3.5	3.5	3.5
SE (mean)	0.1	0.1	0.1	0.1

QPM = quality protein maize, SE = standard error.

Gashe *et al*. (1982) that the nitrogen loss in *tef* dough can be 4–13% depending on the extent of fermentation time; however, this can be avoided by controlling the fermentation time before liquid-solid separation. Therefore, it is very important to keep the fermentation time within the given range. Throughout the trial period, 100% *tef injera* was used as a standard check to make comparisons with various composite flour *injeras* because *tef* is a conventional cereal grain which makes best quality *injera*.

Dabo

Of the total 20 trials, 6 were rejected before being presented to panel members for sensory evaluation. It was observed that the rejected baked products were dry and fragile, sticky, sour, and had unacceptable flavor. The rating system of the evaluation was similar to that of *injera*. The overall acceptability of 100% QPM *dabo* was found to be 3.5 which was better when compared to the conventional maize (3.0). In addition to this, 100% QPM *dabo* was as acceptable as that of 100% wheat. The overall acceptability of QPM-based *dabo* increased the score to 4.4 when 40% wheat was added to 60% QPM. Therefore, the addition of wheat to QPM had a better score as compared to other combinations of cereal grains (Table 3).

Anebabero

All combinations including 80% QPM and 20% wheat, and 80% QPM and 20% sorghum composite flour for *anebabero* were acceptable by the panel members. The scores for all combinations were above 50%, however, when the proportion of barley was above 50%, the score for appearance, texture and flavor progressively decreased; thus, resulted in rejection of the products by the panel members. Therefore, those combinations which scored below 50% were discarded. This rejection was due to bitterness after the sour taste produced in the process of fermentation of the barley. The overall acceptability of 100% QPM and 100% conventional maize *anebabero* was almost similar; 3.12 and 3.11, respectively. However, 100% wheat *anebabero* resulted in a better score 3.90 (Table 4).

Genfo

Good quality *genfo* preparation is highly dependent on the proper processing of the grains. The process involves particular roasting of the raw materials. In the case of barley, if the bran is not fully removed the texture will be affected. On the other hand, over roasting results in a burned flavor. Whereas, under roasting contributes to a raw flavor. Based on the results of the study, acceptable porridge could be prepared by combining the above mentioned cereals in various percentage proportions. As indicated in Table 5, combinations of composite flours *genfo* prepared from QPM and barley, QPM and wheat, and QPM and sorghum were acceptable by the panel members. *Genfo* prepared from 100% QPM had overall acceptability of 3.4. On the other hand, conventional maize-based *genfo* had lower overall acceptability (2.6). These overall acceptability results indicated that QPM is

Table 3. Case summaries for *dabo* (mean score).

Product code	Appearance quality	Texture quality	Flavor quality	Overall acceptance
100% local maize	3.7	3.3	2.9	3.0
50% QPM + 50% wheat	4.0	3.9	3.6	3.6
70% QPM + 30% wheat	4.1	3.7	3.6	4.1
100% wheat	4.1	3.9	4.1	4.1
90% QPM + 10% wheat	3.5	3.1	3.3	3.4
80% QPM + 20% wheat	3.6	3.5	3.3	3.4
85% QPM + 15% wheat	4.3	3.9	4.0	4.0
60% QPM + 40% wheat	4.6	4.5	4.4	4.4
80% QPM + 20% rice	3.9	3.2	2.8	3.1
80% QPM + 20% cassava	3.6	2.6	3.0	2.9
80% QPM + 20% sorghum	4.2	3.7	3.8	4.0
100% QPM	4.0	3.6	3.3	3.5
70% QPM, 20% wheat, 10% sorghum	3.9	3.6	3.5	3.7
70% QPM,20% wheat, 10% barley	3.9	3.5	3.4	3.6
Mean	4.0	3.6	3.5	3.6
SE (mean)	0.1	0.1	0.1	0.1

QPM = quality protein maize, SE = standard error.

Table 4. Case summaries for *anebabero* (mean score).

Product code	Appearance quality	Texture quality	Flavor quality	Overall acceptance
100% QPM	4.3	3.3	3.1	3.1
80% QPM + 20% *tef*	4.0	3.8	3.7	3.7
70% QPM + 30% *tef*	4.2	3.3	3.6	3.6
50% QPM + 50% *tef*	4.5	3.6	3.3	3.6
80% QPM + 20% wheat	4.2	3.6	3.5	3.7
50% QPM + 50% barley	3.6	3.5	3.7	3.5
80% QPM + 20% barley	3.0	3.1	3.0	3.2
100% local maize	3.1	2.9	3.0	3.1
80% QPM + 20% sorghum	3.9	3.4	2.9	3.0
50% QPM + 50% rice	4.7	4.4	4.1	4.2
80% QPM + 20% rice	4.1	3.6	3.6	3.4
100% wheat	4.2	3.9	3.6	3.9
80% QPM, 10% wheat + 10% rice	4.1	3.9	3.7	3.8
80% QPM, 10% wheat + 10% barely	3.6	3.7	3.5	3.6
80% QPM, 10% wheat + 10% cassava	3.3	3.4	3.2	3.3
Mean	3.9	3.6	3.4	3.5
SE (mean)	0.1	0.1	0.1	0.1

QPM = quality protein maize, SE = standard error.

an appropriate grain for the preparation of *genfo* (Table 5). The overall acceptability of *genfo* prepared from 30% and 20% sorghum mixture with QPM resulted in a low score 2.7 and 2.9, respectively, when compared to 100% barley (4.1) (Table 5).

Conclusion

The present study focused on the application of suitable traditional food preparation methods on QPM for the purpose of comparing its nutritional quality, proximate analysis, and sensory evaluation with that of conventional maize and other cereal grains with high acceptability by the consumers. Various combinations of *injera*, *dabo*, *genfo* and *anebabero* were prepared. Unlike the conventional maize, QPM-based foods were highly preferred by the panel members for their taste and superior baking quality that resulted in soft and less fragile *injera* and *dabo*. QPM-based *injera* also stayed longer without having much effect on its softer texture when compared with the conventional maize and it was also observed that QPM developed a less sour taste during the fermentation process. This improved functional property of QPM makes it more

Table 5. Case summaries for *genfo* (mean score).

Product code	Appearance quality	Texture quality	Flavor quality	Overall acceptance
100% QPM	4.0	3.7	3.1	3.4
50% QPM + 50% barley	3.4	3.6	3.8	3.9
100% barley	4.4	3.9	4.2	4.1
100% local maize	3.2	2.9	2.8	2.6
80% QPM + 20% barley	3.7	3.8	3.5	3.5
70% QPM + 30% barley	3.5	3.5	3.5	3.5
80% QPM + 20% wheat	4.3	3.8	3.2	3.7
70% QPM + 30% wheat	4.3	3.8	3.2	3.5
80% QPM + 20% rice	3.3	2.8	2.7	2.7
70% QPM + 30% rice	3.2	2.8	2.7	2.9
80% QPM + 20% cassava	4.3	4.0	3.9	4.2
70% QPM + 30% cassava	4.3	3.7	3.7	3.8
80% QPM + 20% *bula*	3.9	3.6	3.2	3.3
70% QPM + 30% *bula*	4.3	3.7	3.4	3.7
80% QPM + 20% sorghum	2.8	2.9	3.4	2.9
70% QPM + 30% sorghum	2.2	2.3	3.0	2.7
QPM + milk	3.9	3.8	3.8	3.8
90% QPM + 10% *tef*	3.3	3.1	2.9	3.1
QPM + meat + *kale* (*kurkufa*)	4.5	4.5	4.7	4.5
QPM + beans + *kale* (*kurkufa*)	4.5	4.6	4.4	4.5
QPM + kale (*kurkufa*)	4.6	4.5	4.3	4.4
QPM + chilli	4.7	4.4	4.1	4.4
QPM + groundnut	3.7	3.7	3.3	3.4
QPM + sesame	2.8	3.0	2.6	2.8
QPM + potatoes	4.6	4.2	3.7	3.8
QPM + potatoes + groundnut	4.4	3.9	3.8	3.7
Mean	3.9	3.6	3.5	3.6
SE (mean)	0.1	0.1	0.1	0.1

QPM = quality protein maize, SE = standard error.

palatable and can increase the utilization of QPM in the preparation of complementary foods. Similarly, it was found that *genfo* made from QPM was smoother as compared with the conventional maize. The overall acceptability of *genfo* prepared from conventional maize was also significantly lower as compared to that of QPM mixed with 20% wheat.

Generally, to ensure household food security and reduce malnutrition among children, the utilization of QPM through improved processing needs more focus. Based on its nutritional value and functional properties, QPM should be adopted as a staple diet in Ethiopia and for the formulation of complementary foods for infants and young children.

Challenges and Recommendations

A community-based questionnaire was prepared to identify the basic constraints to the use and consumption of maize. Accordingly, some constraints that prevent the wide utilization of maize were identified as follows:

- Due to the food habits of the people, maize is not being used extensively for the preparation of traditional foods especially in the highland areas where the staple crop is *tef*, wheat, barley, etc.
- The traditional preparation methods of maize for consumption are tedious, time and energy consuming and drudgery to the housewives
- The preparation of complementary foods for infants and young children from maize and other crops (legumes, oil seeds, etc) is not well established by the general population

- The traditional processing methods of maize to prepare *injera, dabo* (bread), etc. are time and energy consuming. However, in all surveyed areas the community suggested that maize should be processed mechanically for better utilization
- Processing of maize for commercial purpose has not yet been successfully promoted
- The fuel consumption for cooking maize grain is very high compared to other cereal grains
- Milling to obtain the required smaller particle size is also a problem
- There is a lack of awareness of processing maize for animal feed etc. (Asrat *et al*., 1998)

To overcome the above-mentioned constraints it is crucial to examine means of introducing simple processing methods for utilization of maize.

The production of partially refined flour from cereals (maize, sorghum, wheat, barley, etc.) can be carried out either at household level or in commercial milling establishments. Mortar and pestle perform traditional decortications of grain. However, this method leads to the loss of nutrients (protein, fat, minerals, vitamins, etc.). In addition to this, the process is time consuming and tedious compared with mechanical processing. Therefore, installing milling machines by the cooperatives and/or any individual in areas where maize is the major food crop is important. For *tef* flour preparations, soaking, pounding or dehulling are not essential. However, for maize, when preparing flour for *genfo*, the grain should be lightly roasted in order to develop a pleasant aroma, taste and to improve the keeping quality of the flour. To ensure household food security and reduce malnutrition among children, apart from increasing production, the utilization of maize through improved processing needs more attention by both large scale production as well as at household levels.

Based on its nutritional value and functional properties, QPM is recommended to be adopted as a staple diet in Ethiopia and for the formulation of complementary foods for infants and young children. It is also very important to work towards various QPM-based processed food products which could easily be marketable and a means of income generation.

Acknowledgements

The project team gratefully acknowledges the Ethiopian Health and Nutrition Research Institute for its all round support towards the success of this study. The financial and technical assistance by CIMMYT is greatly appreciated. Further support by SG2000 through their agricultural experts and development agents are very much valued. Finally, the Ethiopian Institute of Agricultural Research is acknowledged for providing quality protein maize grain.

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Industrial Use of Maize Grain in Ethiopia: A Review

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Introduction

Maize (*Zea mays* L.) plays an important role in the diet of millions of people because of its capacity to produce a large amount of dry matter per hectare, its ease of cultivation, versatile food uses and storage characteristics. It is the number one staple food in Africa with about 90% used as food, except in South Africa where only 50% is used as food. In southern Africa, maize provides 50% of the calories with a per capita consumption of over 100 kg. In eastern Africa, it provides 30% of the calories with about 100 kg of per capita consumption. In west and central Africa its consumption is 23 kg per capita, providing 13% of the calories (Eicher and Byerlee, 1997).

World maize production in 2008 was estimated at 823 million metric tons. Of which 39% was harvested in the USA and 15% in China (FAO, 2009). Generally, maize grain has three possible uses: as food, feed and raw material for industry. As a food, the whole grain, either mature or immature, may be used; or the maize may be processed by dry or wet milling techniques to give a relatively large number of intermediary products. These days producers grow maize varieties for specific uses (Table 1).

In most of the developed countries 80% of the harvested maize is fed to livestock. The rest is processed into food and other industrial products. On the other hand, most of the maize produced in developing countries is processed into indigenous foods. In Latin America, maize is generally processed into tortillas, arepas, couscous, polenta and various meals, which are the base for many traditional foods (Serna-Saldivar *et al.,* 1990). In Africa and Asia maize is generally dry-milled into grits (or meals) and flours for the production of flat breads, i.e., roti, maize bread, *injera*, unfermented and porridges (*Tô, Ugali,* and *genfo*), steamed foods (couscous, rice like maize grits), snacks (popped maize) and alcoholic and nonalcoholic beverages (Steinkraus, 1983; Nago *et al*., 1990).

The major chemical component of the maize kernel is starch, which provides up to 72–73% of the kernel weight. Other carbohydrates are simple sugars present as glucose, sucrose and fructose in amounts that vary from 1 to 3% of the kernel. The starch in maize is made up of two glucose polymers: amylose, an essentially linear molecule, and amylopectin, a branched form. The products of maize using dry milling include flaking grits, coarse, medium and fine grits, coarse or granulated meal, fine meal and maize flour. Flaking grits are used for the manufacture of the ready to eat breakfast cereal 'maize flakes'. Grits from yellow and orange maize are preferred. Coarse grits and medium grits are used in the manufacture of cereal products and snack foods. Fine grits are used in brewing. Maize porridge, made from fine grits or coarse meal (flour), and flavored with cheese, is called polenta. Coarse or granulated meal is used in pancake and muffin mixes, maize snacks, cereal products and other bakery uses. Fine meal (with granular size of particle less than 0.2 mm) is used for making maize bread and in bakery mixes, infant foods and breakfast cereals. Maize flour uses include bread and pancake mixes, infant foods, biscuits, wafers, as filler and carrier in meat products, and in breakfast cereals.

Table 1. Different maize types and end uses.

Type	Uses
Waxy maize	Contains 100% amylopectin starch. Starch is used as a stabilizer/thickener in the food industry and as an adhesive in the paper industry. Very little is currently grown.
Flint and dent maize	Hard types (flint), mainly used for human nutrition. Dent maize is softer than flint maize, used as a livestock feed and also to make processed foods.
Yellow dent maize	High vitamin A content, high feed value. Of all cereal grains it has the highest carotene content (Vitamin A). Contains 75% amylopectin and 25% amylose starch.
Soft maize	Well adapted for starch production. Kernels consist almost entirely of soft starch.
Pop or puff maize	Produced mainly for snacks but also has potential for packaging materials.
Sweet maize	Synthesizes low molecular weight polymers and sugars. Contains almost 70% water and more natural sugar than other types of maize. Grown almost exclusively for human consumption (fresh or processed).
High amylose maize	More than 50% amylose content, the starch is used in textiles, candies and adhesives.
High oil maize	Contains 7–8% oil, 2–3% more than dent maize
High lysine maize (quality protein maize; QPM)	Have increased levels of two amino acids (lysine and tryptophan) that are essential in non-ruminant diets.

Establishments in maize wet milling are engaged primarily in extraction of starch, protein, fiber, oil and further refined into dozens of feed ingredients, sweeteners, alcohols, food additives, and other products. Starch is sold to industrial users as modified or specialty starch; processed into sugars and sweeteners like maltose, glucose, liquid and solid sugars, and high-fructose maize syrup (HFCS); or distilled into ethyl alcohol for beverages, fuel, or pharmaceutical uses. Modified starches are manufactured for various food and trade industries for which unmodified starches are not suitable. For example, large quantities of modified starches go into the manufacture of paper products as binding for the fiber. Organic acids and their salts are obtained by fermenting maize syrup or enzyme-treated starch. Acids and salts include citric acid, widely used in pharmaceuticals and foods; glutamic acids and their salts, including monosodium glutamate, that are important food-flavoring agents; and lysine, an essential amino acid used in animal feed. Maize-based starches, sugars, acids, alcohols and other products are used in making paper, pharmaceuticals, textiles, paints, cleaning solutions, and other items. Maize oil extracted from the germ is used as cooking oil. Residuals from processing hulls, fiber, germ meal, gluten, distillers, dried grains and steep-water are used as feed ingredients (Fig. 1).

Although maize is known for its versatile uses, its benefit in most developing countries including Ethiopia is not yet well exploited. Most of the produce is used for traditional food preparation and little is used for industrial purposes. In recent years, a number of food and feed processing industries using maize in various proportions have emerged in Ethiopia. Therefore, this paper attempts to highlight the status of industrial uses of maize in the country and suggests the future direction.

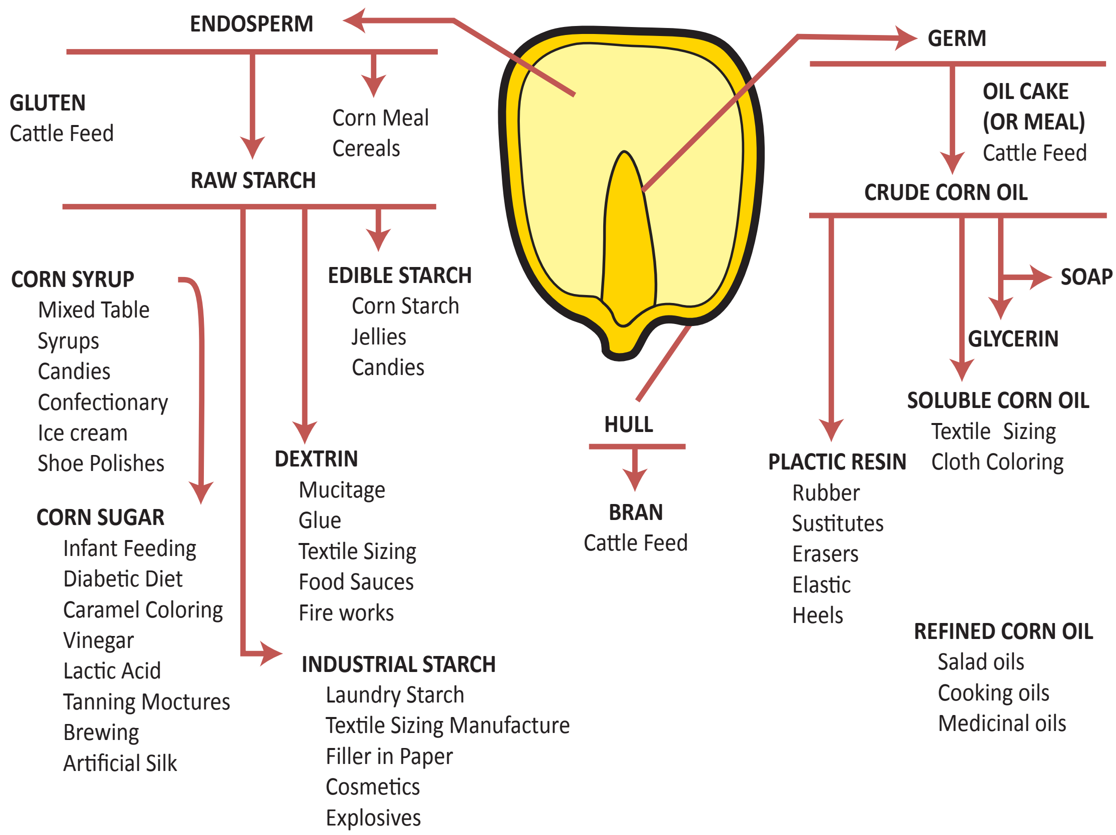

Figure 1. Industrial use of maize grain.

Status of Maize as Industrial Raw Material in Ethiopia

Maize is one of the cereals which provide calorie requirements in the traditional diet. Most of the produced maize is used in several traditional foods such as *injera, kitta, genfo, kollo, nifro* and a local beverage called *tella,* the most common foods in maize growing areas (Senayit, 1992). According to the Household Income, Consumption and Expenditure Survey conducted by the CSA (2010), un-milled maize consumption per household was 62.9 kg for rural areas and 9.3 kg for urban areas, annually. The total consumption per household for rural and urban areas was 145.5 kg and 41.3 kg, respectively. The total country level consumption was 130.4 kg. The quantity of milled and un-milled maize consumption is presented in Tables 2 and 3.

Table 2. Household consumption of milled and un-milled maize (kg)

Expenditure item	Urban	Rural	Country level
Un-milled maize (per household)	9.3	62.9	55.1
Milled maize (per household)	41.3	145.5	130.4

Table 3. Total urban and rural milled maize consumption

Area	Household units	Milled maize consumption	
		Per household (kg)	Total (t)
Urban	1,652,429	41.3	68,255
Rural	9,812,265	145.5	1,428,047
Total	11, 464, 688	130.4	1,495,178

The manufacturing sector is at an initial stage of development with a mere contribution of 6.3% to gross domestic product (GDP) of the country. Within the manufacturing sector, the food processing sub-sector is the largest sub-sector, accounting for 20% of the total gross value of production (GVP) and 34% of the value added to market price (VAMP) of the large and medium-scale manufacturing industry (LMSMI), which itself contributes 69% of the GVP of the manufacturing sector. In 2006/07, as the dominant manufacturing sub-sector, the food processing industry included 13 industrial groups consisting of 381 factories of which 35 factories belong to the public and 346 factories are private holdings. The food processing sector absorbs 46,443 employees (28,623 employees work in public and 17,820 employees work in private holding factories) with a total paid-up capital of Birr 18.5 billion (CSA, 2010).

Of these food processing industries, there are more than eight factories that use maize grain as a raw material to process into relief infant food mixes and snacks (Table 4). The largest quantity of products of the relief food mixes are purchased by World Food Program (WFP), and the remaining amount is procured by governmental and non-governmental organizations. For instance, WFP procured 42,368, 29,339 and 37,704 metric tons of FAMIX (relief food mix made from mainly maize and soybean) in 2007, 2008 and 2009, consecutively (personal communication).

The maize food product processing factories consume more than 50,000 metric ton of maize grain annually and the use of maize as a raw material is increasing steadily from year to year (Table 4). There are also new

Table 4. Maize-based food product processing factories and their special products.

Factory name	Specialty of the factory	Maize use per annum, (t)	Trend of maize consumption	Products for sale	Variety specific	Problems encountered to use maize
Guts Agro-industry	Cereal infant food	7,000	Increasing	Lembo, Famix	No	Low grade
East African Group	Supplementary food	6,700	Increasing	Famix, CSB	No	Low grade due to improper storage
Health Care Food Manufacturers, PLC	Supplementary food	18,000	Increasing	Famix, Famix BMS, Berta	No	High moisture content, insect damaged
FAFA PLC.	Weaning and fortified food	8,000	Increasing	Famix, Cornflex	No	Insect damaged
SEKA Business Group PLC	Supplementary food	8,000	Increasing	Famix, Cornflex	No	Low grade
Oromia Federation maize processing plant	Maize flour	5,000	Increasing	Maize flour, grits	No	–
Total		48,200				

products, such as Lembo snack, breakfast cereals and cornflakes, produced by some factories penetrating into the Ethiopian market. The feed processing sectors also use maize grain as raw material for feed product development. There are more than six factories that consume about twenty thousand metric tons of maize grain annually (Table 5).

The supply of maize grain from producers and other actors is not adequate and is inefficient due to different reasons like poor storage conditions that caused pest infestation, not variety specific, poor quality or low grade. However factories that deal with Ethiopian Commodity Exchange (ECEX) do not have the above-mentioned problems. The main criterion for selection of raw materials, other than Ethiopian standards, is the color of the grain, whether it is white or yellow (red). A variety as a prerequisite for quality selection criteria is not aware by processors, producers and suppliers.

Table 5: Consumption of maize in feed processing factories.

Feed processing factory name	t/annum
Genesis	240
Alema	2,400
Elfora	10,000
Kaliti feed processing	540
Akaki feed processing	3,000
Total	16,180

Conclusions and Future Direction

Even though there are different released maize varieties in terms of color, yield and agro-ecological merits, these varieties are not fully utilized by the farmers and processors. Moreover, maize processors do not have adequate knowledge about quality difference among different maize varieties for processing. So far the only selection criterion for processors to purchase maize as raw material is color. Therefore, there is a need to scale up and out maize varieties aggressively to producers with all stakeholders' contribution. There is also a need to sensitize processors and traders on the characteristics of maize varieties.

The maize breeding program is one of the strongest programs in the Ethiopian Institute of Agricultural Research (EIAR). The program has released different varieties for different agro-ecological zones. However, there are no released varieties which are suitable for specific uses like popcorn, sweet corn, high amylose corn, high oil content maize, etc. Hence, the program has to make plans for releasing those specific maize varieties depending on the demand and priority.

The use of maize as a raw material for agro-industries is very low as compare to the amount of its production and compared to the industrial use of wheat in Ethiopia. As a result, it does not encourage surplus maize production due to insufficient demand. In most of the developed and some developing countries the demand for maize as raw material for industrial use is increasing tremendously. Even though there is a growing trend of maize-based food and feed processing factories in Ethiopia, the number of those factories is still in single digits and their annual consumption of maize grain is not large. Therefore, there is a need to aggressively encourage investors and processors to process maize into industrial products for the local and international market.

Most food processing industries established so far are mainly supplying relief through nutritious food to the World Food Program (WFP). They do not sell their products in local shops and supermarkets, with the exception of a few. In addition, the technology they use is just dry milling and particularly milling whole grain. However, the agro-processing sector like food, textile and paper is growing fast. Those factories may use maize starch and starch derivatives in the future. Therefore, investors should be encouraged to engage in maize wet milling processing plants.

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Improving the Fodder Contribution of Maize-Based Farming Systems in Ethiopia: Approaches and Some Achievements

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Introduction

Since its introduction, maize has gained significance and at present ranks first in total production and grain yield among cereals. The total annual production and productivity of maize surpasses all other cereal crops, although it is exceeded by *tef* in area coverage (CSA, 2010). Compared with other cereal crops, it produces the greatest proportion of residues, which could serve as an important source of fodder for ruminant livestock. In this paper, the contribution of maize as fodder in maize-based farming systems in Ethiopia, and approaches and some achievements in improving maize fodder are discussed.

Appraisal of Approaches for Improving the Fodder Contribution of Maize

Varietal selection for fodder yield and quality

Literature provides evidence showing the existence of genetic variations in yield and quality of cereal crop residues. Studies conducted by Adugna *et al.* (1999), for example, showed varietal differences in grain and stover yields, and stover quality in maize and suggested that there was potential for developing maize varieties that combine high grain yield and desirable stover quality traits. This shows that there are prospects for breeding and selection programs in favor of both traits provided that crop breeders, agronomists and animal nutritionists undertake concerted research efforts. With this backdrop, a study was carried out to appraise three maize varieties (hybrids: BH660, BH540 and open-pollinated variety; OPV, Kuleni) for grain and residue yield and fodder quality at Bako Research Center in the western part of the country (Diriba, 2005).

Grain yield, stover fractions and stover quality traits were assessed and varietal differences were observed to be significant for these attributes in all fractions except the husk. Grain and leaf yields were significantly highest for BH660. The cob and total residue yields were lowest for BH540 and in most cases values with a narrow range of differences were observed for BH660 and Kuleni. The values for harvest index were highest for BH540, intermediate for BH660 and lowest for Kuleni. Narrow inter-varietal differences for harvest index were observed for the hybrids and the values were generally higher when compared with Kuleni (data not shown). Digestible crop residue yield was higher for BH540 followed by Kuleni and BH660 in a decreasing order (Table 1).

Regarding the quality parameters, significant varietal effects were observed for ash, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and in vitro dry matter digestibility (IVDMD). By and large, the study revealed that the hybrids had

Table 1. Effect of variety on maize grain yield, yield components, harvest and potential utility indices, crude protein and digestible crop residue yields of three maize varieties (n = 10).

	Maize varieties		
Yield components	**Kuleni**	**BH660**	**BH540**
Grain (t ha^{-1})	7.9 ± 0.2b	9.9 ± 0.2a	8.0 ± 0.2 b
Cob (t ha^{-1})	1.7 ± 0.1a	1.6 ± 0.1a	1.3 ± 0.1b
Stalk (t ha^{-1})	4.0 ± 0.2a	3.6 ± 0.2a	2.6 ± 0.2b
Leaf (t ha^{-1})	2.4 ± 0.1b	2.9 ± 0.1a	2.1 ± 0.1b
Husk (t ha^{-1})	1.3 ± 0.1	1.1 ± 0.1	1.2 ± 0.1
Total residue (t ha^{-1})	9.4 ± 0.4a	9.2 ± 0.4a	7.2 ± 0.4b
Harvest index (%)	45.7 ± 1.0b	52.0 ± 1.0a	52.7 ± 1.0a
Potential utility index (%)	67.5 ± 1.4b	71.6 ± 1.4b	78.2 ± 1.4a
Digestible crop residue yield (t ha^{-1})	3.8 ± 0.3ab	3.8 ± 0.3b	3.9 ± 0.3a
Crude protein yield (kg ha^{-1})	261.0 ± 15.3a	254.0 ± 15.3a	195.0 ± 15.3b

Source: Diriba (2005). Means within rows followed by different letters vary significantly.

higher grain yield compared with the OPV. Rankings of varieties were consistent for harvest index, potential utility index, and digestible crop residue yield, the order being BH540>BH660>Kuleni. The same was also true for ranking varieties using NDF, ADF and IVDMD. Ranking order of the varieties was observed to be consistent for stalk, total residue, crude protein (CP) and CP yield; the ranking order being Kuleni>BH660>BH540. The hybrid variety BH660 ranked first in grain yield and consistently ranked second for most of the important quality traits suggesting the possibility of selecting for varieties that combine higher grain yield with desirable quality traits (Table 2).

Evaluation of defoliation time and intensity

In maize-based farming systems, removal of maize leaves following pollination or silk senescence for livestock feed is widespread especially in the eastern Harage area (Senait and Dejene, 1992). If the practice is applied at a strategic time and in such a way that the grain component is not significantly affected, the harvested leaves could be used as a source of quality fodder. A huge quantity of the dry matter (DM) in maize grain comes from photosynthesis that takes place subsequent to flowering (Allison and Watson, 1966). It is noticeable that the effects of manipulation of assimilate supply depend on the stage of grain development. It was reported that when applied at silking, leaf removal decreases the rate of total DM accumulation (Frey, 1981).

Defoliation treatments limiting carbohydrate supply decrease grain yield for the most part by diminishing the number of kernels per ear via precocious ending of kernel development in the apical part of the ear (Tollenaar and Daynard, 1978). Tollenaar (1977) has also indicated assimilate reduction through partial leaf removal to have little effect on kernel growth rate when imposed after the final number of kernels per ear has been established but reduces kernel weight at maturity due to reduced duration of grain filling. In the work being assessed, it was hypothesized that post-silking stress through topping and defoliation of leaf parts for animal feed production purposes could result in variable effects depending on the degree and time it was imposed. The study was carried out to explore the effects of varying degrees and time of leaf defoliation on maize grain, residue yield and nutritive value of the defoliated foliage and crop residue at grain harvest.

Table 2. Effect of variety on ash (% dry matter; DM), crude protein (CP; %DM), fiber components (neutral detergent fiber; NDF, acid detergent fiber; ADF, acid detergent lignin; ADL and ADF-ash, in g/kg) and in vitro dry matter digestibility (IVDMD; %DM) of three maize varieties (n=10).

	Varieties		
Variables	**Kuleni**	**BH660**	**BH540**
DM	90.0 ± 0.3	89.8 ± 0.3	89.8 ± 0.3
Ash	4.3 ± 0.3b	4.4 ± 0.3b	5.6 ± 0.3a
CP	2.8 ± 0.2	2.8 ± 0.2	2.7 ± 0.2
NDF	741.3 ± 8.5b	772.5 ± 8.5b	867.2 ± 8.5a
ADF	442.3 ± 6.4b	458.4 ± 6.4ab	463.9 ± 6.4a
ADL	44.7 ± 2.2b	52.6 ± 2.2a	47.9 ± 2.2ab
ADF-Ash	16.5 ± 2.3	17.2 ± 2.3	17.0 ± 2.3
IVDMD	40.2 ± 1.4b	44.8 ± 1.4b	53.9 ± 1.4a

Source: Diriba (2005). Means within row followed by different letters vary significantly.

An open-pollinated maize variety named Kuleni was used for this study. Three defoliation time treatments: 15, 30 and 45 days after 100% silking and three intensities of defoliation *viz*. removing the lower half of all the leaves below ear placement; all leaves below ear; and all plant components above ear, were assessed. In this experiment, ear leaf was not detached. For the treatment in which all plant components above ear were removed, defoliation was accomplished by cutting those plant parts above ear at the node just next to ear placement. Leaves below ear were defoliated at their junction with the sheath, thus leaf yield at defoliation denotes leaf blade only. The total annual fodder yield was determined by summing the leaf yield obtained by defoliation and the total stover collected at grain harvest.

The study revealed that grain yield was higher for the treatment where all leaves below ear were stripped and lower values were obtained for the treatment in which all plant components above ear were removed. A slight reduction in maize grain yield due to removal of the upper leaves as compared to the lower ones implies that the upper leaves are more important than the lower ones. This outcome is in harmony with the results reported elsewhere (Senait and Dejene, 1992). The DM yield of the cob component was also lowest when the top parts were removed. On the other hand, significantly higher stalk, leaf at grain harvest, and maize residue at grain harvest were obtained for the treatment in which lower half of leaves below ear were harvested. This may perhaps be ascribed to their inconsequential contribution to production of assimilates that are partitioned to these components, in view of the fact that most of the lower half of leaves below ear were dry at harvest. The yield of leaves at removal was superior for the harvesting system in which all components above ear were removed and lower for the one where the lower half of leaves below ear were harvested (Table 3).

With regard to the time of leaf removal, higher mean grain yield was achieved for defoliation treatment of 45 days after 100% silking when pooled over years. A narrow range of values was observed for the other yield components when averaged over years. Pooled over years and degrees of defoliation, significantly lowest yields were recorded for all traits except leaf DM yield at defoliation when leaf removal was imposed 15 days after 100% silking. Grain, cob, leaf yield at grain harvest and green leaf yield were superior for the treatment in which defoliation was imposed after 45 days. On the other hand, mean DM yields were highest for stalk, husk, and maize residue at grain harvest and total annual residue when defoliation was imposed 30 days later.

The effect of degrees of defoliation was not significant for crude protein, ADF and ADL fractions (Table 4). Conversely, effect of degree of defoliation was significant for NDF and IVDMD. The CP concentration of plant parts above ear was rather lower; which may be attributed to dried tassel fraction and stalk components that are relatively lower in CP compared with the leaf blades. The relatively lower values for protein concentration in the lower half of leaves below ear could be associated with the fact that the greatest proportions of the leaves were dry at harvest. The NDF values were significantly lower for above ear components and comparable values were observed for the lower half of the leaves below ear and all leaves below ear. The IVDMD values followed a similar fashion as that of CP concentration.

The influence of time of harvest was not significant (P>0.05) for CP, ADL and IVDMD but was significant for NDF and ADF. Crude protein showed a declining trend with ripeness and this was in conformity with reports of Diriba (2000) and Keftassa (1990) for other grass species. A narrow range of values for different harvesting time treatments were observed for NDF and ADF concentrations and an increasing trend with time of maturity was observed for ADL. The IVDMD values ranged from 54.0 to 56.3%; the highest value being for samples harvested at 30 days and the lower being for the treatment in which leaf removal was imposed 45 days after 100% silking (Table 5).

Table 3.The effect of degrees and time of leaf defoliation on maize grain (t ha^{-1}) and other yield components (t ha^{-1}) of maize.

	Extent of defoliation					Days to defoliation after 100% silking				
Variable	Lower half	All below	All above	SE	Significance	15	30	45	SE	Significance
Grain	7.9	7.9	7.2	2.7	NS	7.2b	7.6b	8.3a	1.7	*
Cob	1.6	1.5	1.3	0.1	NS	1.4	1.5	1.6	0.0	NS
Stalk	4.6a	3.9b	3.8b	0.1	**	3.6b	4.5a	4.2a	0.1	**
Leaf at grain	2.8a	1.9b	2.0b	0.1	**	2.2	2.2	2.3	0.1	NS
Husk	1.3	1.4	1.3	0.1	NS	1.2bc	1.5a	1.3b	0.0	*
Maize residue	10.4a	8.7b	8.4c	0.2	*	8.4b	9.6a	9.4a	0.2	**
Total annual forage	10.9	10.1	10.8	0.3	NS	10.0b	10.9a	10.9a	0.2	**
Leaf yield at removal	0.5c	1.4b	2.5a	0.0	**	1.5a	1.4b	1.5a	0.0	**

Source: Animal Feeds and Nutrition Division, Bako Agricultural Research Center. SE = standard error, NS = not significant, * = significantly different at P ≤ 0.05, ** = significantly different at P ≤ 0.01. Means within rows followed by different letters vary significantly.

Table 4. Effect of extent of and days to defoliation on crude protein (CP), fiber component concentrations and in vitro dry matter digestibility (IVDMD) of defoliated maize leaves.

	Extent of defoliation			Days to defoliation			Extent of defoliation		Days to defoliation	
Variable	Lower half	All below	All above	15	30	45	SE	Significance	SE	Significance
CP (%DM)	8.8	10.1	7.1	10.4	8.7	6.9	1.5	NS	1.5	NS
NDF (%DM)	62.2b	62.2b	61.9a	62.0b	61.8b	62.5a	26.9	**	26.9	*
ADF (%DM)	37.6	33.6	34.7	35.0b	35.4b	35.5a	19.0	NS	19.0	*
ADL (%DM)	3.3	3.0	3.9	2.9	3.1	4.2	3.9	NS	3.9	NS
IVDMD (%DM)	57.4a	57.5a	50.9b	54.0	56.3	55.4	1.5	**	1.5	NS

Source: Animal Feeds and Nutrition Division, Bako Agricultural Research Center. NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin, DM = dry matter, SE = standard error, NS = not significant, * = significantly different at P ≤ 0.05, ** = significantly different at P ≤ 0.01. Means within rows followed by different letters vary significantly.

Table 5. Crude protein (CP), fiber components and in vitro dry matter digestibility (IVDMD) of maize stover at grain harvest as influenced by extent and days to leaf removal.

Variable	Extent of defoliation: Lower half	Extent of defoliation: All below	Extent of defoliation: All above	Days to defoliation: 15	Days to defoliation: 30	Days to defoliation: 45	Extent of defoliation: SE	Extent of defoliation: Significance	Days to defoliation: SE	Days to defoliation: Significance
CP	2.7	2.6	2.8	2.7	2.4	2.9	0.2	NS	0.2	NS
NDF	74.3	71.2	76.6	74.7	72.5	74.9	19.6	NS	19.6	NS
ADF	44.5a	44.5a	44.0b	44.4	45.2	43.3	13.3	*	13.3	NS
ADL	4.3	4.5	4.7	4.2	4.7	4.6	3.4	NS	3.4	NS
IVDMD	40.2	40.8	40.2	40.5	39.9	40.8	1.0	NS	1.0	NS

Source: Animal Feeds and Nutrition Division, Bako Agricultural Research Center. NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin, DM = dry matter, SE = standard error, NS = not significant, * = significantly different at P ≤ 0.05, ** = significantly different at P ≤ 0.01. Means within rows followed by different letters vary significantly.

All entities (P>0.05) except ADF (P<0.05) were not significantly affected by degrees of defoliation. The concentration of CP was relatively higher for the residue samples collected from plots in which all leaves above ear (2.8%) and lower half of leaves below ear (2.7%) were removed and this could possibly be due to the higher leaf proportion at grain harvest. The IVDMD values varied from 40.21 to 40.78%, the highest value being for the plots in which defoliation was imposed at 30 days. Correspondingly, time of harvest had no significant (P>0.05) effect on all residue quality parameters. Generally, the CP concentration and IVDMD values of the residue samples at grain harvest with variable degrees and time of defoliation history were very low; and the fiber components were high indicating the inadequacy of intake for animals subsisting on these low quality roughage diets.

Plant population density manipulation

As crop production continues to invade the grazing lands, animals are forced to depend on smaller marginal grazing areas and roadside pasture resources. The nutritional constraint to the productivity of the livestock resource of the country is at present not only limited to the dry season as has been thought in the past but also a problem throughout the wet months of the year. Therefore, during both the rainy and dry seasons, animals depend almost solely on *in situ* crop residue and aftermath grazing especially immediately following crop harvest. Thus, the problem of feed scarcity is logically serious during those periods when most of the land is covered by crops. This obviously calls for strategies and development options to alleviate this temporal feed resource scarcity both in terms of quality and quantity.

Farmers in different parts of the country have developed a range of coping mechanisms in reaction to the recurring feed resource scarcity. Fekadu and Alemu (2000) have reported that farmers in the Harage area use thinnings of maize and sorghum as important sources of fodder for their livestock. They further reported that these thinnings contributed about 89.2, 84.5 and 67.4% to the fattening diet of oxen during July, August and September, respectively. Sorghum thinnings were also reported to have a significant contribution to fattening rations of the area especially during the early dry season of critical feed shortage. These feed resources from cultivated fields are the result of the intentional increment of the seed rate meant to achieve higher plant population density so as to compensate for removal of diseased and stunted crop stands for use as fodder.

This indigenous practice offers an opportunity to manipulate the agronomic practices of maize and sorghum geared towards improving the feed availability in maize-based farming systems in the medium and high altitude highlands of Ethiopia. In this study it was hypothesized that using a plant population density higher than the recommended sowing rate followed by systematic reduction of the plant density could offer a potential alternative approach to improving feed supply during the wet season. The trial was implemented to appraise the effect of time of removal of the intentional more than average maize stands on grain yield and yield components, and in addition, the yield and quality of harvested green forage as well as maize residue at grain harvest.

The study was conducted in 2001 and 2002 cropping seasons using a maize variety BH660. A spacing of 50 cm between plants within row and 80 cm between rows with two plants per hole and a fertilizer rate of 92/69 kg ha^{-1} N/P_2O_5 was used. The P source (diammonium phosphate; DAP) was all applied at planting and split application was used for the N source, urea, half at planting and half at 6 weeks after planting.

Six treatments were evaluated in this study. The first treatment was a control treatment where recommended plant population density for the indicated variety, within and between row spacings and levels of fertilizer as described before with 20 plants per row (2 plants per hill × 10 hills per row). For the other five treatments, reducing the spacing between plants of 50 cm to 25 cm doubled the number of plants per row and for all plots the spacing between rows was kept at 80 cm. The additional plants imposed were then removed at 4, 6, 8, 10 and 12 weeks after maize emergence, making a total of six treatments with the control. All extra plants from the middle two rows were removed at the indicated removal time (40 plants = two rows × two plants per hole × 10 plants per row). At removal, plants were cut at ground level and weighed in the field using a field balance and sub-samples were dried at 60°C for 72 h in forced draught oven to determine the DM yield and sub-samples pooled over replications were retained for laboratory analysis. At grain maturity, two middle rows were harvested for the determination of grain yield at 12.55% moisture content and the stover was partitioned into different stover components

Grain yield exhibited a consistently declining trend with delay in harvesting time of the extra plants (Table 6). Grain yield was significantly higher for the control treatment where the recommended plant population density was used followed by the plots harvested 4 weeks after emergence of maize when averaged over years. The falling trend in grain yield with belated harvesting time is in effect associated with competition for growth resources with increasing plant population density. Husk yield also declined consistently with late harvesting implying reduction of cob size due to the intra-plant competition for resources. Forage yield of extra plants generally increased with time but within treatment, variation between the two cropping seasons, was not wide. Averaged over years, significantly highest forage biomass was obtained at 12 weeks followed by that of 10 weeks. Maize residue yield at grain harvest was highest for the control treatment during 2001 and for the treatment where harvesting was done at 4 weeks during 2002, but no consistent trend was observed with time of harvest.

By and large, total annual forage yield was observed to be higher for the later harvesting schemes. When compared with the control, total annual forage yield reduction of 11.0 and 8.8% was observed for the 6 and 8 week harvesting time, for 2001. When extra plants were harvested at 10 and 12 weeks, a forage yield increment of 10.6 and 39.9% was observed as compared to the control treatment.

Regarding the nutrient profiles, the crude protein and IVDMD concentrations were higher for green harvested samples compared to the samples taken at maize grain harvest. The samples collected from the extra plants contained 571.4% more CP as compared to the samples collected at grain harvest. In the same way, the samples composed from the extra plants had IVDMD values with 31.0% advantage compared to the samples collected at grain harvest. Fiber components were inferior for the green harvested samples as compared to the samples collected at grain harvest (Tables 7 and 8).

Table 6. Main effects of year and time of removal treatments on grain and husk components (t ha^{-1}) of maize.

Year	Grain yield	Leaf at grain harvest	Husk	Extra plant fodder	Total residue at grain harvest	Total annual forage
2001	8.7	3.4	0.8	3.3	9.6	12.3
2002	7.2	2.9	0.9	3.1	8.7	11.3
SE	2.9	0.1	0.0	0.1	0.3	0.3
Significance	*	*	NS	NS	NS	NS
Treatments						
Control	9.6	3.7	1.2	__	10.6	10.6
4 weeks	9.1	3.7	1.1	0.5	10.8	11.0
6 weeks	8.0	3.4	0.9	1.1	8.7	9.9
8 weeks	7.9	3.0	0.9	2.7	9.2	11.9
10 weeks	6.8	2.7	0.7	4.8	7.8	12.6
12 weeks	6.5	2.5	0.7	7.0	7.7	14.7
SE	2.3	0.2	0.07	0.2	0.4	0.5
Significance	**	**	**	**	**	**

Source: Animal Feeds and Nutrition Division, Bako Agricultural Research Center. SE = standard error, NS = not significant, * = significantly different at P ≤ 0.05, ** = significantly different at P ≤ 0.01.

Table 7. Chemical compositions and in vitro dry matter digestibility (IVDMD) of green harvested maize fodder (% of dry matter).

Treatments	Crude protein	NDF	ADF	ADL	IVDMD
Control	–	–	–	–	–
4 weeks	25.8	61.6	27.9	1.8	77.4
6 weeks	17.6	61.4	33.5	2.7	70.7
8 weeks	12.0	64.6	38.1	2.9	67.9
10 weeks	11.6	68.7	40.1	3.1	68.1
12 weeks	25.7	58.6	27.7	1.7	75.0
Mean	18.5	63.0	33.5	2.4	71.8

Source: Animal Feeds and Nutrition Division, Bako Agricultural Research Center. NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin.

Table 8. Chemical compositions and in vitro dry matter digestibility (IVDMD) of dry harvested maize fodder (% of dry matter).

Treatments	Crude protein	NDF	ADF	ADL	IVDMD
Control	2.5	76.8	40.8	3.4	54.4
4 weeks	3.8	74.2	39.2	4.2	55.2
6 weeks	3.0	76.7	44.4	4.3	54.7
8 weeks	2.3	78.3	47.2	4.4	55.2
10 weeks	2.5	77.9	45.8	4.5	53.9
12 weeks	2.5	79.2	46.6	5.1	55.8
Mean	2.8	77.2	44.0	4.3	54.9

Source: Animal Feeds and Nutrition Division, Bako Agricultural Research Center. NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin.

Integrating forage and maize production to intensify land use

Forage legumes recover the soil N content that could be exploited for crop production (Tarawali, 1991). Others (see for example Buresh *et al.*, 1993) have extensively documented the use of this concept to augment the yield of succeeding crops. Maize grown on lands previously under fodder banks of *Stylosanthes* species was reported to give higher yields than that of natural fallow or continuously cultivated land (Mohammed-Saleem and Otsyina, 1986). These findings confirmed the vital role of forage legumes in addition to their importance as supplementary feed for ruminants subsisting on low quality diets (Kouame *et al.*, 1992). The commonly available evidence is based on sole grown legumes to evaluate the potential residual contribution to the succeeding cereal crop.

In effect, the role of forage legumes in improving the soil N pool and performance of the following crop could be influenced by quite a lot of factors. Tarawali and Mohammed-Saleem (1995) have pointed out that age-induced invasion of the legume field by nitrophilous grass species may possibly diminish the N accessible to subsequent crop (Mohammed-Saleem and Otsyina, 1986). This is because of the uptake of the fixed N by grass. For grass and legume mixed system, Mallarino *et al.* (1990) have reported that legume-dominant swards are needed to take full advantage of fixed N yields for red clover–tall fescue and birds foot trefoil–tall fescue mixtures.

The present study was conducted against the background that there is little research that examined the use of planted legume/grass leys for animal production and the restoration of soil fertility for increased maize production in Ethiopia. The aim was to evaluate the grain yield and yield components; and the chemical composition and IVDMD of maize residue following *Panicum* and *Stylosanthes* mixed pasture grown at variable seed proportions of the two components. The stand was grown at different relative seed proportions for 3 years. Initially, the study was planned to study the performance of the constituent species and assess the biological yield advantages of grass-legume mixed cropping. This phase was completed in mid-December 2001 and Diriba (2003) has reported the results of the three year study. Following the completion of the grass and legume mixture study in December 2001, the plots were cultivated using a hoe three times before the onset of rain and all the plant parts, roots and stubbles, of about 10 cm height remaining from the previous study were properly worked into the soil. Each plot with different cropping history was then divided into two; one of the plots received fertilizer rate recommended for maize production in the study area (75/75 N/P_2O_5) and the other without any additional fertilizer. A fallow land adjoining the experimental blocks was included as a control, resulting in seven treatments: the soil that had been cropped for three years with pure *Stylosanthes* (T1), 25 P:75 S mixture (T2), 50 P:50 S mixture (T3), 75P:25 S mixture (T4), pure *Panicum* (T5), 100 P:100 S (T6) and fallow land which was under natural pasture for at least 6 years adjoining the experimental blocks (T7). The treatments were arranged in a split-plot design; the main plots being the plot history and the subplots the fertilized (75/75 N/P_2O_5) and unfertilized (0/0 N/ P_2O_5) treatments.

A maize variety named Kuleni was used for this study. The crop was planted using an intra- and inter-row spacing of 25 and 75 cm, respectively. At maturity, the ears from all standing plants of each subplot treatment (6 m^2) were harvested to determine the grain yield at 12.5% moisture content. The stover was partitioned into all plant components to determine DM yield. Finally, all stover components including husk and cob were combined and a composite sample was taken for laboratory analysis. In the sections to follow the results of this trial are described.

Mean yield for grain, cob, stalk and total residue as influenced by year and plot history treatments are shown in Table 9. Higher grain yield (8.1 t ha^{-1}) was recorded for 2001 as compared to 2002 (7.6 t ha^{-1}) season and small differences were observed between the two years for cob. Significantly higher DM yield of stalk was obtained during the 2001 (3.1 t ha^{-1}) season as compared to that of 2002 (1.9 t ha^{-1}). For total residue DM yield, the difference between the two years was not significant but a slightly higher total residue was obtained during 2001 season (8.8 t ha^{-1}) as compared to that of 2002 (8.5 t ha^{-1}). The lower grain yield observed in the present study during the second year as compared to the first year is in agreement with the findings of Tarawali (1991) who reported lower overall maize grain yield during the second year as compared to the first year in an experiment in which residual contribution of *Stylosanthes* fodder banks was studied.

Significantly (P<0.01) highest grain yield was recorded for the plots that were under 75 *Stylosanthes* and 25 *Panicum* mixed pasture and the lowest mean grain, cob, stalk and total forage yields were observed for the plots that were under natural pasture (Table 9). During 2001, significantly highest leaf biomass was recorded from the pure *Stylosanthes* plots. During the 2002 season, plots under 75 S:25 P gave the highest mean leaf yield. For the husk component, highest mean DM yield was recorded from the plots in which the two forage species were grown at 100:100 proportions. In 2002, the highest husk component yield was recorded from the 75 S:25 P plots. Fertilizer application significantly affected all the measured traits. For all traits, the fertilized plots gave superior yield when compared with the unfertilized plots (Table 10).

With reference to the chemical composition and IVDMD concentrations of the residue samples, residue samples were collected for the fertilized and unfertilized subplots within the fallow treatments during 2001 only. In general, the CP content is very low, far below 8% and the total cell wall component, as measured by the NDF concentration was high and the values for IVDMD were moderate under both fertilized and unfertilized conditions (Table 11). The effect of plot history was significant for CP, ADL and IVDMD of whole maize residue. The NDF values were high, ranging between 82.6% for the plots that were under pure *Stylosanthes* to 86.9% for those that were under the natural pasture fallow. The ADF was high for 25 S:75 P and was lowest for the natural pasture fallow plots. On the other hand, IVDMD values were significantly lower for the 100 S:100 P plots and highest for 25 S:75 P ones.

Table 9. The effect of year and mixture treatments on maize grain, cob, stalk and total residue yield.

Year	Grain	Cob	Stalk	Total residue
2001	8.0	1.4	3.1	8.8
2002	7.6	1.5	1.9	8.5
SE	1.5	0.1	0.1	0.2
Significance	NS	NS	**	NS
		Treatments		
T1	8.0	1.5	2.5	9.1
T2	8.5	1.5	2.3	8.8
T3	7.6	1.3	2.5	8.5
T4	8.2	1.6	2.8	8.6
T5	8.0	1.5	2.9	9.1
T6	8.3	1.6	2.7	9.3
T7	5.9	1.2	2.1	7.0
SE	3.1	0.1	0.1	0.3
Significance	**	NS	**	NS

Pure *Stylosanthes* (T1), 25 P:75 S mixture (T2), 50 P:50 S mixture (T3), 75P:25 S mixture (T4), Pure *Panicum* (T5), 100P:100 S (T6) and fallow land which was under natural pasture for at least 6 years adjoining the experimental blocks (T7). SE = standard error, NS = not significant, * = significantly different at P ≤ 0.05, ** = significantly different at P ≤ 0.01.

Table 11. Effect of fertilizer application and grass–legume mixed fallow on crude protein (CP), fiber components and in vitro dry matter digestibility (IVDMD; %) of maize residue.

Fertilizer	CP	NDF	ADF	ADL	IVDMD
Unfertilized	2.5	84.4	43.9	4.3	53.0
75/75N/P_2O_5	2.4	86.1	45.0	4.6	53.1
SE	0.1	9.0	5.6	0.8	2.2
Significance	NS	NS	NS	NS	NS
			Treatments		
T1	3.2	82.7	45.4	5.7	57.6
T2	2.4	83.7	45.2	5.6	53.9
T3	2.4	85.8	44.8	4.5	55.1
T4	2.1	85.7	43.0	3.7	59.4
T5	2.6	86.3	44.0	3.8	55.6
T6	2.3	85.7	45.0	4.5	74.6
T7	2.1	86.9	44.0	5.5	55.5
SE	0.2	16.9	10.5	1.5	4.0
Significance	*	NS	NS	**	*

NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin, SE = standard error, NS = not significant, * = significantly different at P ≤ 0.05, ** = significantly different at P ≤ 0.01. Pure *Stylosanthes* (T1), 25 P:75 S mixture (T2), 50 P:50 S mixture (T3), 75P:25 S mixture (T4), Pure *Panicum* (T5), 100P:100 S (T6) and fallow land which was under natural pasture for at least 6 years adjoining the experimental blocks (T7).

Table 10. Effect of fertilizer application on yield and other yield components of maize.

Traits	Unfertilized (t ha^{-1})	75/75 N/P_2O_5 (t h^{a-1})	SE	Significance
Grain	7.2b	8.5a	1.6	**
Cob	1.3b	1.6a	0.0	**
Stalk	2.2b	2.8a	0.1	**
Leaf	1.2b	3.5a	0.1	**
Husk	1.2b	1.6a	0.0	**
Total residue	7.7b	9.6a	0.1	**

SE = standard error, ** = significantly different at P ≤ 0.01. Means within rows followed by different letters vary significantly

Evaluation of normal and quality protein maize as poultry feed

Maize is the most important energy source in monogastric animals like poultry. Although it is primarily considered as the supplier of energy, it contains considerable amounts of protein. However, the quality of protein in normal maize is highly deficient in the critical amino acids, tryptophan and lysine. Quality protein maize (QPM) varieties have higher tryptophan and lysine contents and two times more nutritive value than normal maize varieties. These amino acids are essential to poultry since they are unable to synthesize their own. Feeding trial results on poultry and pig supported superiority of QPM over normal maize. It has been shown that feeding QPM to poultry or grower pigs reduces requirements of high protein ingredients such as fishmeal, sustains feed quality and reduces production costs thereby increasing profit margins compared to normal maize.

The National Maize Research Program released one QPM hybrid (BHQP542) that has comparable yield advantage to the normal maize variety BH540. This provided the opportunity to investigate the nutritional merit of the QPM versus normal maize varieties. Therefore, this experiment was conducted to determine the protein quality of QPM for other protein sources, and demonstrate the nutritional advantage of the same as a substitute for normal maize in broiler rations. The following discussion is based on trials implemented at Debre Zeit Agricultural Research Center.

The first trial dealt with the effect of increasing normal maize replacement levels with QPM. In this study, starter and finisher rations were formulated with QPM replacing 0, 25, 50, 75 and 100% normal maize (NM), with all other ingredients remaining constant. Three hundred mixed sex day-old broiler chicks of similar body weight were used. The chicks divided into five groups of 60 chicks each. Each group was further sub-divided into three replicates with 20 chicks per replicate and placed in the experimental pens at 10 chicks per square meter density. The treatment rations were randomly assigned to the pens. Birds were provided daily with a known amount of feed *ad libitum* and water was offered freely. Feed intake and group body weight were measured on daily and weekly basis, respectively. Mortality was recorded as it occurred. A completely randomized design was used and data were analyzed using SAS software. Starting body weight was used as a covariate while analyzing the finisher phase data.

The results of the trial on the incremental replacement of QPM for NM indicated that replacement of 75% of NM with QPM gives the highest final body weight during the starter phase (Table 12). This level also resulted in the best daily gain and feed conversion ratio.

Table 12. Performance of broilers fed diets containing increasing levels of quality protein maize.

Treatments	Percent normal maize replaced					SE	Significance
	0	25	50	75	100		
				Starter phase (0–28 days)			
Mean feed intake (g/bird/day)	45.4	46.0	46.0	49.0	45.8	2.0	NS
Initial body weight (g/bird)	43.1	43.5	43.7	43.7	43.4	0.3	NS
Final body weight (g/bird)	709.2ab	711.8ab	705.1ab	773.6a	701.9b	21.4	*
Gain/bird (g)	666.2ab	668.3ab	661.5ab	739.9a	658.5b	23.7	*
Daily gain (g/bird/day)	23.8ab	23.9ab	23.6ab	26.4a	23.5b	0.9	*
Feed conversion ratio (feed: gain)	1.9ab	1.9ab	1.9ab	1.9b	2.0a	0.0	*
				Finisher phase (29–56 days)			
Mean feed intake (g/bird/day)	115.6	130.7	136.9	123.4	121.3	7.1	NS
Initial body weight (g/bird)	709.3ab	711.8ab	705.1ab	773.6a	701.9b	21.4	*
Final body weight (g/bird)	2,018.4	2,209.3	2,165.3	2,206.5	2,049.2	82.6	NS
Daily gain (g/bird/day)	46.8	53.5	52.2	51.2	48.1	2.3	NS
Feed conversion ratio (feed: gain)	2.5	2.5	2.6	2.4	2.5	0.1	NS
				Whole period			
Mean feed intake (g/bird/day)	80.5	88.3	91.3	86.2	83.2	4.2	NS
Initial body weight (g/bird)	43.1	43.5	43.7	43.7	43.4	0.3	NS
Final body weight (g/bird)	2,018.4	2,209.3	2,165.3	2,206.5	2,049.2	82.6	NS
Daily gain (g/bird/day)	32.3	38.7	37.9	38.6	35.8	1.5	NS
Feed conversion ratio (feed: gain)	2.3	2.3	2.4	2.2	2.3	0.1	NS

SE = standard error, NS = not significant, * = significantly different at $P \leq 0.05$. Means within rows followed by different letters vary significantly.

However, during the finisher phase the best final body weight and daily gain was achieved by replacing 50% of the NM with QPM.

In the second trial, three rations containing 10% CP were formulated to test the protein efficiency ratio of QPM. The first ration was formulated using NM. The second ration comprised equal proportions of NM and QPM (50:50) and the third was formulated using QPM alone. A total of 90 chicks were used in this trial with 30 chicks per treatment. The treatments were replicated thrice. The result indicated that protein efficiency ratio was significantly improved as a result of including equal proportions of NM and QPM (50:50) instead of using either NM or QPM alone in broiler rations. Chicks feeding on rations with equal proportions of NM and QPM were better in terms of final body weight, daily gain, feed conversion ratio and protein efficiency ratio (Table 13). Generally, QPM was found to be a better source of protein compared to normal maize.

Conclusion

Breeding and selection programs in maize have nowadays taken into consideration the feed values of residues and there are initial results depicting occurrence of genetic variations among varieties in grain and stover yields, and stover quality (high in both protein content and digestibility) in maize and suggesting that there are potentials for developing maize varieties that combine high grain yield and desirable stover quality traits. Breeding efforts with maize have come up with varieties with exceptionally superior food/feed value. The varieties known as QPM have higher contents of tryptophan and lysine amino acids, and twice as much nutritive value as normal maize varieties. In feeding trials with broiler chicken, QPM based rations have resulted in higher final body weight, daily gain, feed conversion ratio and protein efficiency ratio when compared with normal maize varieties. Therefore, incorporation of attributes such as nutritional value (CP and amino acid content, digestibility) of grain and residues in maize varietal selection indices can bring about significant value additions to the conventional grain-based breeding and selection practices.

Several techniques of crop husbandry and utilization have been identified for maize that help integrate crop and livestock sub-sectors in the predominantly smallholder mixed farming system especially in regions where maize is more productive. Apart from efficient use of the stover, techniques of exploiting the standing crop either wholly (by thinning) or partially (leaf stripping) have been identified through meticulous agronomic manipulations. Findings indicate that in maize crop stands where the plant population is higher than average, thinning of excess plants for early use as animal fodder four weeks after emergence of maize did not significantly affect maize grain yield. Another agronomic study on early use of maize crop stands revealed that grain yield was not significantly affected when maize plants were stripped of the lower half leaves for use as fodder during the latter half of the cropping season when animal feed supply is critically low. This practice has been shown to have least effect on grain yield when it is accomplished 45 days after 100% silking.

Another promising system of integrating the smallholder crop and livestock farming has been through introducing legume fodder crops in maize production either by temporal (crop rotations) or spatial (mixed cropping) arrangements that optimize plant interaction. For example a precursor fodder bank consisting of *Panicum*/*Stylanthes* mixture had positive effects on maize grain yield and yield components as well as on the chemical composition and IVDMD of the residue.

Table 13. Performance and protein efficiency ratio (PER) of broiler starters (0–28 days) fed diets containing increasing levels of quality protein maize (QPM).

Parameters	NM	50:50 (NM:QPM)	QPM	SE	Significance
Mean feed intake (g/bird/day)	13.7	17.9	17.8	1.4	NS
Initial body weight (g/bird)	43.3	42.5	42.5	0.4	NS
Final body weight (g/bird)	151.0b	214.4a	214.0	16.8	*
Gain/bird (g)	107.7b	171.8a	171.5a	16.7	*
Daily gain (g/bird/day)	3.9b	6.1a	6.1a	0.6	*
Feed conversion ratio (feed: gain)	3.6a	2.9b	3.0b	0.1	**
PER (gain/protein intake)	2.8b	3.8ab	4.2a	0.4	*

NM = normal maize, SE = standard error, NS = not significant, * = significantly different at $P \leq 0.05$, ** = significantly different at $P \leq 0.01$. Means within rows followed by different letters vary significantly.

Future direction in maize research and development in regards to animal feed should give emphasis to:

- Varietal selection for those that combine traits for residue fodder quality and digestibility besides quality protein grain.
- Integrating maize and fodder legumes in several applications to exploit their synergic role in sustainable income generation as well as in environmental protection.
- Mechanical and chemical manipulation of maize residues (both cob and stover) to improve their feeding value.

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Salient Proceedings of the Third National Maize Workshop of Ethiopia

Date: April 19–20, 2011

Venue: Ethiopian Institute of Agricultural Research (EIAR) Hyruy Hall, Addis Ababa

List of Participants: Attached at the end of the document

Agenda

1. Welcome address
2. Opening address
3. Keynote address
4. Maize exhibition
5. Presentations on progress during the past decade, and opportunities for further research and development in different disciplines
6. General discussion
7. Closing remarks

1. Welcome address

Dr. Solomon Assefa, the Director General (DG) of EIAR, welcomed all the participants. In his official welcome address, Dr. Solomon Assefa mentioned the timeliness of the conference as it coincided with the growth and transformation plan (GTP) launched by the Government of Ethiopia (GoE). He underlined the importance of maize in agricultural transformation in Ethiopia. Only 25% of maize area in Ethiopia is covered by improved seed. This proportion is low and there is a need to work harder to further extend the area coverage of improved seeds.

Dr. Solomon mentioned that maize research in Ethiopia began in 1952 and has passed through various development stages since then. Several hybrid and open-pollinated varieties (OPVs) have been released and are being grown by the farmers. The DG further indicated that CIMMYT has been providing strong support to the national maize research of Ethiopia in terms of germplasm, materials support and capacity building. Hence the successes achieved in maize research of the country are the product of joint efforts.

Dr. Solomon appreciated the array of topics to be covered during the workshop period, as these topics cover the whole range of research, seed, extension, development and marketing issues. The DG requested the participants to further strengthen the partnership among all the actors in the maize value chain systems in future endeavors. He extended his gratitude to all participants for giving their time and travelling long distances to attend this important workshop.

2. Opening address

Mr. Wondirad Mandefro, State Minister, Ministry of Agriculture, Government of Ethiopia, officially opened the workshop. In his opening remarks, Mr. Wendirad expressed great pleasure for having been invited to officially open the workshop. He pointed out the contribution of agriculture to the overall livelihood, gross domestic product (GDP), export earnings and national employment of Ethiopia. He also emphasized the importance of maize to the country, and urged the participants to come up with focused recommendations to significantly increase maize productivity and production in Ethiopia.

3. Keynote address

A keynote address was given by Dr. Benti Tolessa, the former maize breeder and national maize team leader of Ethiopia. He indicated the developmental stages through which the Ethiopian maize research program passed from the 1980s to the 2000s. The 1980s was marked by the release of the first hybrid maize variety in Ethiopia. He mentioned that in the 1990s, three hybrids were released using east African lines and CIMMYT materials as source germplasm. The 2000s were ear marked by the release of quality protein maize hybrids, release of low moisture stress tolerant varieties, conversion of BH660 to QPM version, and development and release of highland maize varieties.

Subsequently, Dr. Adefris T/Wold, Director, Crop Research Process of EIAR and Dr. Mosisa Worku, National Maize Research Coordinator made presentations on the topics 'Values fostering greater efficiency in partnership between EIAR and the Consultative Group on International Agricultural Research (CGIAR) centers on maize research of Ethiopia' and 'The status and future direction of maize research and production in Ethiopia,' respectively. At the end of this session, a presentation titled 'Maize production and marketing: Producers, traders and policies' was given by Dr. Dawit Alemu, Coordinator, Socioeconomics and Agricultural Extension Coordination unit of EIAR.

Comments/suggestions:

- The efforts made by the national maize research, extension and development team for fostering maize R&D in Ethiopia was highly appreciated.
- The development and release of BH661 as an alternative to BH660 was highly gratified. Also, BH660 can still perform as it did in the old days if planted under good management; and hence, it can be available as an alternative variety.
- More efforts should be placed on the screening and development of maize streak virus (MSV) resistant varieties that can adapt to Gambella areas.
- It was mentioned that maize seed production guidelines were prepared and are freely available for use by any interested parties.
- Technology provision to farmers should be a "menu approach" in which we give options to farmers and they choose what they need among those available.
- In Ethiopia there are better resources and qualified researchers; hence, more can be achieved in the future in maize research and development.
- The average national yield of maize seems low. This is because maize consumed as green cobs are not considered, and also the average includes all areas; otherwise, it could have been higher than what has been reported currently.
- Future maize agronomy research should consider the micronutrient needs of the crop.
- Maize plant population management in farmers' fields has received low attention, and this negatively affects the crop yield.
- In one of the presentations, maize marketing as food and feed was highlighted; however, maize market demand for industrial use has not been indicated. This point has to be critically considered during the final submission of the document.
- Germplasm sources for highland maize are limited. Highland maize breeding should get good attention during the next 10 years.
- Maize is currently traded under the Ethiopian Commodity Exchange (ECX); however, this aspect was not covered in Dr. Dawit's presentation. This most useful aspect needs to be presented in the final paper.
- Price volatility is one of the most important factors affecting maize production among the farming community; clear policy recommendations need to be presented in this line.
- Questions were raised with regard to future variety release system, encouraging private companies and licensing a given variety to one seed company. It was agreed that national agricultural research systems (NARS) should support and encourage private seed producers as it is clearly stated in the policy of the GoE. However, the issues related to variety release systems and variety licensing should be worked out at the MoA level.

4. Maize Exhibition

The participants visited an exhibition of maize varieties, products of maize processing industries (food, feed), different foods from maize (dishes prepared by the Ethiopian Health and Nutrition Research Institute (EHNRI) and Melkasa Nutrition Section), chemicals, organic storage structures and machinery used for planting and processing maize. The Maize Exhibition, with active participation of both public and private institutions in Ethiopia, was much appreciated by all.

5. Presentations on progress and lessons learnt during the past decade, and opportunities for further research and development in different disciplines

Breeding and genetics

Nine presentations were made in this session as follows:

a) Genetic improvement of maize for mid- and low-altitude sub-humid maize agro-ecologies of Ethiopia
b) Maize improvement for low-moisture stress areas of Ethiopia: Achievements and progress in the last decade
c) Development of highland maize germplasm for highland agro-ecologies of Ethiopia
d) Molecular breeding and biotechnology for maize improvement: CIMMYT's perspective
e) Breeding for quality protein maize
f) Development of improved yellow maize germplasm in Ethiopia
g) Recent advances in breeding maize for enhanced pro-vitamin A content
h) Breeding maize for food-feed traits in Ethiopia
i) Dual-purpose crop development, fodder trading and processing options for improved feed value chains

Discussion

- Morka is released for long rainy season areas like Jimma, Bonga etc and it was popularized by Jimma Agricultural Research Centre

- As 142-1-e is a synthetic of sister lines, it was strictly maintained in isolated fields and breeders at Bako are carrying out maintenance of this material in well isolated areas.
- Regarding highland maize germplasm it is important to limit the real number of fixed inbred lines and also indicate clearly the pedigree and heterotic pattern.
- Following the presentation on "Molecular breeding and biotechnology for maize improvement: CIMMYT's perspective" by Dr BM Prasanna, Director, Global Maize Program, CIMMYT, the following issues were raised: Do CIMMYT have protocols for doubled haploid (DH) technology? What is Bt maize? Participants were informed that CIMMYT has recently developed DH protocols in collaboration with the University of Hohenheim, Germany. Presently, the team is engaged in developing second-generation, tropicalized haploid inducers with freedom-to-operate, so that the technology can be effectively transferred to the national partners.
- The attempt done so far to replace male parent of BHQP542 (based on CML176) was not successful and studies are still on-going to replace it.
- Recent advances in breeding maize for enhanced pro-vitamin A content: this issue raises the questions: Can pro-vitamin A be maintained for a long time if the grain is stored for a long time? Can we maintain pro-vitamin A in the field? How does it perform when there is contamination with other maize? The presenter responded that if we store the grain under high temperatures there is high probability of losing pro-vitamin A. However, it is possible to maintain it for long periods under good storage conditions since 90% of the pro-vitamin A is found in its endosperm. Studies are still going on to find out varieties with high retention capacity of pro-vitamin A. Like other qualities there is chance of losing pro-vitamin A under production areas. However, we can have production villages to avoid high field contamination as with that of QPM villages.

Maize agronomy

Eight review papers were presented as follows:

a) Review of research results for striga management in maize production
b) Review on crop management research for improved maize productivity in Ethiopia
c) Soil fertility management for maize production in Ethiopia: A review
d) Conservation agriculture for sustainable maize production in Ethiopia
e) Towards sustainable intensification of maize–legume cropping systems in Ethiopia
f) The potential impact of climate change—maize farming system complex in Ethiopia: Towards retrosetting adaptation and mitigation options
g) Review of weed research on maize in Ethiopia
h) Review of agricultural mechanization research technologies for maize production in Ethiopia

Discussion

- There is a need to strengthen technology transfer, especially the imazapyr resistant (IR)-maize technology developed at Pawe.
- Soil fertility management research needs to be continued for enhancing maize production, involving diverse disciplines (breeders, soil microbiologists), considering the dynamics of changes in varieties, and changing production practices.
- There is a need to include economic analysis for the results obtained.
- Attention should be given to other micronutrients, especially zinc and copper, besides N, P and K.
- The technology of tillage practices should be delivered to farmers not as a separate technology but as one of the conservation agriculture components since the integration of tillage and other CA practices result in better productivity.
- Evaluation of stalk borer damage on maize under maize–legume cropping system should be done where the pest is important.
- Climate change issues raise the questions: Were the models validated? What will be the advice to maize breeders to cope with decreasing rainfall predicted in the western part of the country? The presenter responded that model validation was done using historical data validation and down scaling. He also advised maize breeders to search for early maturing and stress tolerant maize varieties by focusing on population breeding techniques and development of deep rooted maize cultivars.
- Better awareness creation among the farming community and their involvement in weed management technology generations were suggested.
- There is a need to change the structures of the storage materials to reduce losses, construction materials (wood) should also be given due attention considering the scarcity of wood.
- There is an unavailability of farm implements and a weak relationship between the research centers and farm implement manufacturers.

Maize protection

The following four presentations were made:

a) Maize pathology research in Ethiopia: A review
b) Review of past decade research on pre-harvest insect pests of maize in Ethiopia
c) Review of past decade research on post-harvest insect pests of maize in Ethiopia
d) Pest risk analysis for maize importation into Ethiopia: A case of eight source-countries

Discussion

- There is need to promote on-farm storage technologies after harvest, both for food security and price stability.
- The incidence of maize streak virus (MSV) should be taken seriously and investigated thoroughly.
- Since there is shift of insect pests and pathogens, periodic and coordinated surveys across the country should be done.
- Regarding research on pre-harvest insect pests, why only stem borers and termites? Attention should be given to others also, like aphids.
- Why not Bt approach for management of stem borers in Ethiopia? It is the policy issue and the Ethiopian Government has not yet allowed the use of the Bt technology. Bt technology needs a careful approach.
- The risk analysis of maize should be both after importation and from the sources. Focusing on one direction is not important. The priority should be given to sources of importation of materials rather than after importation of the materials.
- The issue of large grain borer: Different suggestions were made about the control of larger grain borer from the audience. Finally, they were agreed on formation of groups of people or a committee to discuss the issues and reporting for the concerned bodies (Ministry of Agriculture). In addition, the concerned bodies must create close contact with the quarantine people to monitor the pest regularly.
- The issue of quarantine needs close attention to generate successful results.

Socio-economics and extension

The following presentations were made:

a) Maize production and marketing in Ethiopia: The producers, traders, and the policies (presented during the first session)
b) Advances in participatory on farm maize technology demonstration and promotion in Ethiopia
c) Maize technology transfer: Experiences of the Ministry of Agriculture
d) Input supply for maize production in Ethiopia
e) Experience of SG2000 in maize extension
f) An old wine in a new bottle: A systems approach for maize–legume cropping systems technology development and scaling out

Discussion

- Comparing Morka with Kuleni and Gibe may lead to erroneous conclusions, because these three OPV maize varieties are in different maturity groups and have different niches. Since every variety has its own recommended adaptation area, in future, comparison should be made between varieties released and recommended for the same maturity group and specific agro-ecology zone.
- The socio-economic development that has been attained since the Second National Maize Workshop should have been analyzed and presented during the Third National Maize Workshop. The impact should also have been analyzed and its implication on technology adoption should also be assessed and analyzed. The commentator has raised some questions such as what choices of technologies have been presented for farmers? Are they available in the market?
- Regarding the Sustainable Intensification of Maize–Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) Project, CIMMYT has no direct linkage with Regional Agricultural Research Institutes (RARIs) and it goes through EIAR. So the issue is up to EIAR to consider RARIs.

5.5 Maize utilization for food and feed

The following presentations were made:

a) Industrial use of maize grain in Ethiopia: A review
b) Improving the fodder contribution of maize-based farming systems in Ethiopia: Approaches and some achievements
c) Development of suitable processes for improving *injera*, *dabo* (bread) and *genfo* (porridge) using QPM in the Ethiopian traditional foods: Emphasis on enhancement of the physico-chemical properties
d) Uses of QPM for preparation of different dishes

Discussion

- There is a need to narrow the existing gap of linking markets to grain producers in different regions of the country i.e., the need for linking demand and supply.

- Regarding the fodder contribution of maize, the authors should be careful regarding conclusions due to the fact that N content of the stover depends on soil nitrogen content but not genetic component of varieties alone.
- There is a fear of early defoliation 15 days after silking due to the importance of leaves for photosynthesis up to grain filling stage.
- There is a need to include non-defoliated maize plants as one treatment in making conclusions.
- It is advisable to involve gender segregation in QPM food preparation and its training.
- Cost analysis for preparation of food is needed.
- Entries repeated in the presentation (parents of BHQY545) will be excluded from full write up.
- QPM promotion is limited to few districts and may be resulting in decreased grain price in the market.

5.6 Maize seed production and distribution

The following presentations were made:

a) Maize seed production and distribution of the public sector in Ethiopia: Progress and challenges
b) The use of Pioneer Maize Hybrid Seeds and its impact on small scale farmers of Ethiopia.
c) Small scale farmers based hybrid maize seed multiplication: A case study in Oromia and the Oromia Seed Enterprise experience
d) Cereal production in Ethiopia and the role of private commercial seed producers in the maize industry
e) Review of maize seed production in Ethiopia: The case of research centers and higher learning institutes
f) Maize seed multiplication: The case of Ethiopian Seed Enterprise
g) Maize seed multiplication: The experience of South Seed Enterprise

Discussion

- The seed and support of seed system and also the regulatory system is weak and must be strengthened. There must be a strong regulatory system (quality control) to differentiate the production of seeds from the grains.
- The control seed in Ethiopia was conducted by MOA in earlier times, but now it is decentralized to regions. In the future, the key issue is to strengthen regional regulatory offices. A lot of work needs to be done. Seed is the DNA of agriculture and without it, it is impossible to increase agricultural production. Therefore, it must be given due attention. Nowadays, many companies are involved in seed production but who is really coordinating these seed producing sectors?
- Some varieties (e.g., TOGA, a very good hybrid) were popularized out of their recommended agro-ecologies i.e., varieties are going to be misplaced in production and popularization. Why? Varieties should be positioned to their adaptation area.
- The OPV is pushed away by the hybrids because of productivity. So who should produce the seeds of OPV? Public seed companies must come out of the profitable side of seed production and place emphasis on other non-profitable seed production slowly.
- Replacement is good for some old varieties but as long as it is in production by farmers and is liked by the farmers, instead of withdrawing the variety, let us give the choice to the farmers.
- Seed production in other African countries is strengthened by the presence of alternative seed companies.

6. General discussion

Application of biotechnology under the existing policy

The following comments/suggestions were made by the participants:

- What are the key biotechnology priorities to support? These need to be clearly identified
- EIAR should consider developing collaborative project proposals on biotechnology with CIMMYT
- Integration of molecular techniques in breeding by using molecular markers is the key for enhancing genetic gains and breeding efficiency
- Strengthening phenotyping tools and protocols is highly critical, rather than focusing solely on genotyping
- Focus on climate change resilient agriculture
- Utilizing biotechnology to know the biotypes/ pathotypes of key insect-pests and pathogens
- It is important to map insects and disease biotype ecosystem diversity
- Regarding DH techniques, CIMMYT may need to develop some training manuals/documents

Questions/comments/suggestions from international scientists regarding GM maize technology

- Are we going to wait to discuss about the potential and relevance of transgenic technologies in maize for Ethiopia until the Fourth National Maize Workshop?
- What are the basic steps and time impediments in terms of policy and capacity?
- Think about what is good for the country and what is good for the farmers, for judicious application of all relevant technologies.

Comments/suggestions from Ethiopian scientists on GM maize

- There is huge potential forGM maize.
- But, it is better to start with non-food crops.
- Biotechnology is not only GM maize; non-GM part will go under existing policies since GM part is a little bit stringent.
- Let us work to convince the policy makers regarding GM maize and seed issues.

Variety options by maturity and type of hybrids (single cross vs three-way cross)

- Quick and faster generation of technology is needed (accelerate breeding program).
- Regarding BH660 type hybrids there is a shortage of germplasm source in this maturity group even in CIMMYT.
- Regarding BH540 series there is no problem in terms of germplasm availability for breeding.
- These types of questions are guided by the appearing environmental situations (adaptation and preference by seed producers and farmers).
- In the future there is a possibility to shift to single cross by improving the *per se* performance of inbred lines.
- For marginal areas there should be potential hybrids.
- Private seed companies may go for release of single crosses.
- Assignment for "diversifying genetic background of late maturing germplasm similar to BH660 series" was given to CIMMYT
- Our breeding direction must focus on development of single cross in the near future.

Larger grain borer (LGB)

- The pest has currently crossed to Ethiopia from Kenya around Moyale.
- Conventional insecticides and storage structure made from wood do not control LGB
- It needs immediate reaction in order to restrict its distribution.
- Coordination, frequent monitoring and close supervision will be needed.
- Pheromone traps should be available.
- Training is needed for entomologists.
- A good proposal on effective control of post-harvest insect-pests, including LGB, should be developed and submitted to the funding agencies.

Deployment of agronomic packages to counter mono-cropping, depletion of soil nutrients, and low yields

- Concentrating on single technology i.e., seed alone, is not effective to increase our production and productivity.
- So far, adequate emphasis was not given to integrated agriculture. Integrated systems should be given greater attention.
- Since other management options are as important as varieties, dissemination works should be also focused on crop management (agronomic and crop protection) options rather than only focusing on variety improvement.
- Fertilizer recommendation to specific areas should be encouraged.
- Issues of soil fertility and natural resource management need attention.
- There is a need to revise recommendation packages for maize production as soon as new technologies are recommended.

Seed system support and coordination

- We need a unit that regulates the seed system from breeder seed up to certified seed.
- At this time, the private sector is weaker as compared to the public ones.
- Licensing issue should be correlated with quality and economic issues.
- Licensing should be on a competitive basis. Simply producing and selling without promotion and demonstration will not continue as it is now.
- It would be a good idea if the private seed companies had access or exclusivity to that variety that has a high potential and is likely to be released, as this would speed up the process of getting seed of these varieties to farmers. The national maize program should advise the government on the issue of exclusivity. This issue will need further discussion.
- EIAR must advise private seed companies to produce their own varieties. But at this time there are no clear ideas for the question "to whom the varieties generated by public research will be licensed?"

Strengthening local private seed companies and farmers' unions

- Government should encourage private seed companies
- There is a chance to help some farmers' cooperatives (unions) involved in seed production but for private seed companies according to Ministry of Finance and Economic Development (MoFED) it is difficult to pass the money to individuals involved in the private sector.

Grain marketing

- Low grain price affects seed production since there is a tendency of farmers to shift to other crops and reject inputs including seed when grain price is very low.
- Organizing local unions and micro-financing should be strengthened.
- A floor price should be practiced immediately, i.e., early announcement of floor price is needed.
- Make farmers aware about the price before the planting of the crop.
- When there is excess production, government should buy the grain and should be responsible for both market stabilization and making farmers aware about timely planning and market information.

7. Closing remarks

In his closing remarks, Dr. BM. Prasanna, Director, Global Maize Program of CIMMYT, thanked all the participants for their very active participation and contribution toward the success of the workshop. He also thanked the Organizing Committee for successful coordination of the workshop. Dr. Prasanna highlighted:

- The importance of intensified efforts to develop stress resilient maize cultivars for future climates in Africa.
- The need for strengthening the participation among various institutions involved in maize R&D in Ethiopia, as working in isolation will not help us to achieve the millennium development goals.
- National partners must take effective advantage of various technological advances that have been happening in maize research in diverse areas, including molecular breeding, genomics, high throughput, low-cost phenotyping, and conservation agriculture, for enhancing maize production and productivity in countries like Ethiopia.
- It is equally important to motivate the youth to take up agricultural research as a profession, in addition to recruiting and training/educating young researchers in modern science and technology.

Dr Prasanna also expressed a strong commitment and support from CIMMYT for strengthening maize research and development in Ethiopia. He remarked that the gap between the Second and Third National Maize Workshops was indeed long! To keep pace with the rapid scientific developments and technological opportunities, he desired that the National Maize Program should consider organizing the Fourth National Maize Workshop in Ethiopia in not more than 3–4 years.

Dr Prasanna also assured the participants of the Workshop that the EIAR and CIMMYT team will work together in bringing out the Proceedings of the Third National Maize Workshop of Ethiopia by the beginning of 2012.

List of participants of the Third National Maize Workshop of Ethiopia

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19.	Chimdo Anchala	Oxfam-America
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ISBN: 978-970-648-184-9