Maize Research Highlights
1999-2000

CIMMYT®

The Maize Program

Contents

Foreword: Going Where the Maize Grows

Few businesses or consumer products are central to the nutrition, livelihoods, and even survival of people in settings as diverse as the Brazilian prairies, the backlands of Bihar, India, northern Mexican deserts at sea level, remote Andean highlands at well above 3,000 meters, landlocked Zimbabwe, or far-flung islands in the Philippines. Maize and maize farming and consumption, however, are common denominators in the lives of all those people and many others in developing countries. The dependence of these farmers and consumers on maize constitutes the reason for the existence of the CIMMYT Maize Program.

Maize is produced on some 100 million hectares in the developing world. In large parts of Africa and Latin America, inhabitants often consume from 0.5 to 1.0 kg of maize each day, obtaining therein the bulk of their carbohydrates and, occasionally, a significant portion of their protein. Demand for the crop in Asia, especially as a component in animal feeds, is rising much faster than the demand for rice or wheat. Either as a high-input, high-yielding commercial crop or, more often, as the anchor in complex, small-scale, low-yielding, rainfed cropping systems operated by subsistence farmers and their families, growing maize is a major economic activity in developing countries.

To help the millions of maize farmers and consumers in the developimg world, the CIMMYT Maize Program goes where the maize is grown. Working out of eight locations in maize-producing regions and four research stations in CIMMYT's host country, Mexico, Program researchers support and catalyze the efforts of many thousands of partners from national maize research programs, private companies, non-government organizations, and farmer associations worldwide.

During 1999-2000, the CIMMYT Maize Program and its partners in maizer esearch systems of developing countries worldwide recorded significant accomplishments in benefit of maize farmers and consumers. Among these were the development, testing, and successful promotion stress-tolerant maize for sub-Saharan Africa and the release of new, high-yielding quality protein maize (QPM) hybrids and varieties in morethan a dozen countries in Africa, Asia, and Latin America.
Two CIMMYT researchers received the 2000 World Food Prize for their leading role during the 1970-80s in the development of QPM. There was a sizeable expansion in the use of CIMMYT highland maize germplasm by

[1] Cali, Colombia; Addis Ababa, Ethiopia; Guatemala City, Guatemala; Delhi, India; Nairobi, Kenya; Kathmandu, Nepal; Lima, Peru; and Harare, Zimbabwe.

seed companies and farmer associations in Mexico, where nearly half the world's 6.3 million hectares of highland maize is grown. Maize Program researchers also homed in on the biochemical bases for resistance in maize to post-harvest storage pests. This should facilitate breeding for this important trait. In Nepal, the Program advanced recently-begun work to develop and deploy productivity-enhancing, resource-conserving technologies for maize farmers in fragile hill environments. Finally, there have been important shifts in Program strategies and approaches in recent years, to better address maize farmers' concerns in a rapidly evolving environment including, among other things, increased emphases on private enterprise and open markets.

The first number in a yearly series designed to keep interested readers abreast of progress in the Maize Program's global research agenda, Maize Research Highlights 1999-2000 provides details and supporting data on the work outlined above, along with contact information for Program researchers and a list of Program publications for the period covered. Given the breadth of Program activities and their long-term nature (meaning advances seldom come in yearly quanta), the Highlights will truly be that—a selection of noteworthy topics that vary from year to year. This edition was compiled and edited by CIMMYT science writer Mike Listman. We hope you find the series interesting and useful, and welcome your comments or other contributions to improve it and to support the research it describes.

General information about the Maize Program or how to request seedor publications is available on CIMMYT's internet page (at www.cimmyt.org). Please feel free as well to contact me or any of ther esearchers in the Program on these points.

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Stress-tolerant Maize for Farmers in Sub-Saharan Africa

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Introduction

Population in sub-Saharan Africa is rising 3% per year, but food production is increasing by only 2%. This net decline in the food supply is being partly met through imports and food aid. However, in many cases, the populace is simply eating less: approximately 100 million people in sub-Saharan Africa are malnourished, 30 million of them children under 5 years of age.

Maize is the region's principal cereal crop. Farmers harvest some 25 million ha of maize each year, producing about 35 million tons of grain. This accounts for 40% of the region's cereal production. Fully nine-tenths of the grain goes directly for human consumption. Of the 23 countries in the world with the highest per capita consumption of maize as food, 16 are in sub-Saharan Africa. Maize provides 50% of the calories in diets in southern Africa, 30% in eastern Africa, and about 15% in West and Central Africa.

Despite its importance as a food crop, most maize in sub-Saharan Africa is grown on small plots as part of complex, low-input systems. Yields average 1.4 t/ha, more than 1.0 t/ha below the average for all developing countries. Farmers' low use of inputs stems partly from a lack of cash (for example, 8 out of 10 rural Malawians have an annual cash income of less than US$15) and partly from the significant risks of crop production. In a given season, crops can be damaged or ruined by one or several important constraints:

- **Drought.** Insufficient or poorly distributed rainfall reduces maize output across the region. Severe droughts periodically destroy entire crops over large expanses. Less than 7% of agricultural area in sub-Saharan Africa is irrigated.
- **Nitrogen depleted soils.** Nutrient depletion and soil fertility decline are widespread in smallholder farming systems, as many farmers cannot afford or do not have access to organic and inorganic fertilizers.
- ***The parasitic weed, Striga spp.,*** reduces maize yields particularly in eastern and western Africa. Increasing soil fertility is the best measure against this pest, but often out-of-reach to resource-poor farmers.
- **Maize stem borers.** These field pests are particularly damaging to plants weakened by one or several of the preceding constraints.

Stress Tolerant Maize Developed under Farmers' Conditions

To increase food security and alleviate poverty among African farm families, in the mid-to-late-1990s CIMMYT and its partners launched two major projects aimed at making maize-based cropping systems in the region more productive and, especially, more efficient in the use of scarce water resources and soil nutrients:

- The "Southern African Drought and Low Soil Fertility Project" (SADLF) features work by CIMMYT researchers and partners[2] in southern Africa, with funding from the Swiss Agency for Development and Cooperation (SDC) and the Rockefeller Foundation. Its central goal is to develop and deploy maize that yields more and has more stable yields under

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* Maize physiologist; ** maize breeder.

[2] Work is supervised by the Southern African Center for Cooperation in Agricultural and Natural Resources Research and Training (SACCAR) of the Southern African Development Community (SADC), and major partners include the national maize research systems of Angola, Botswana, Lesotho, Malawi, Mozambique, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe; leading non-government organizations involved in rural development in the region; and private seed companies.

conditions typical of those faced by resource-poor farmers, without depleting natural resources. It began in 1996 and is now in its secondphase.

- In early 1998 CIMMYT, the International Institute for Tropical Agriculture (IITA), and national agricultural research systems[3] began joint work under the project "Developing and Disseminating Stress-Tolerant Maize for Food Security in East, West and Central Africa" (popularly known as the Africa Maize Stress project, or AMS). Objectives are to 1) develop maize varieties, lines, synthetics, and hybrids with improved yield stability when grown under stress from drought, insufficient soil nitrogen, Striga, and stem borers; 2) promote the dissemination of stress tolerant varieties and hybrids to African farmers; and 3) strengthen the capacity of our partners to achieve the above. Funding through 2000 was provided by the UNDP Regional Bureau of Africa, the UNDP Sustainable Energy and Environment Division (SEED), the Swedish International Development Cooperation Agency (SiDA), and the International Fund for Agricultural Development (IFAD).

Both efforts attempt to bring farmers' conditions and concerns onto experiment stations, essentially developing new varieties and hybrids simultaneously under both stressed and favorable conditions, and advancing only genotypes that perform well in both settings. This approach contrasts with the focus of conventional public and private sector breeding strategies on increasing yields primarily under optimal,well-managed conditions and assuming that such increases will carry over into less productive environments. The stress breeding methodology was developed over more than a decade of research at CIMMYT headquarters, with funding largely from UNDP. Both projects are also developing capabilities for1) innovative, lar ge-scale, on-farm testing and demonstration of promising varieties, and 2)establishing sustainable systems for pr oducing and selling quality seed of stress tolerant maize. Finally, staff of both projects interact continuously and substantively, exchanging germplasm and information to develop useful products for African maize farmers.

Southern Africa

To introduce the stress breeding approach to southernAfrica, SADLF staf f first had to demonstrate its usefulness to researchers strongly wedded to oldpractices of maintaining "well-manicur ed" experiment fields. This was accomplished early on through head-to-head comparisons under managed stress conditionsbetween leading cultivars fr om the region and CIMMYT experimental, stress tolerant genotypes. Though not necessarily adapted to the region, the stress-tolerant materials clearly outyielded the local favorites when exposed to severe drought and low N stress, two common stresses in resource-poor farmers' fields.

The project next helped establish and maintain regional drought and N stress screening sites (Table 1), trained regional scientists, and characterized target environments using geographic information systems (GIS). A few specifics are described below.

GIS Characterization of Environments. To obtain better information on the environments where maize is grown, project staff worked with CIMMYT's GIS and modeling lab and the Blackland Research and Extension Center of the Texas A&M University System,[4] to create the Africa Maize Research Atlas (Hodson et al. 1999). This CD-ROM-based tool makes a range of GIS data readily available for manipulation, analysis, and output as tables, figures, and maps, to

Table 1. SADLF drought and N stress screening sites.

	Low Nitrogen	Drought
Angola	Mazozo	Mazozo
Botswana	Sebele	Maun and Ethsa
Malawi	Chitedze	Chitala
Mozambique	Umbeluzzi	Sussundenga
South Africa	Viljenskroen	
Tanzania	Arusha	Arusha
Zambia	Golden Valley, Kabwe	Nanga
Zimbabwe	Harare	Save Valley, Chiredzi

[3] Participating countries are Benin, Burkina Faso, Burundi, Cameroon, Congo, Côte d'Ivoire, Ethiopia, Ghana, Guinea, Kenya, Madagascar, Mali, Nigeria, Rwanda, Senegal, Sudan, Tanzania, Tchad, Togo, and Uganda. The AMS works in partnership with the West and Central Africa Collaborative Maize Network (WECAMAN) operating under the sub-regional organization, the Conférence des Responsables de Recherche Agronomique Africains (CORAF), and the East and Central Africa Maize and Wheat Network (ECAMAW) of the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA). Finally, as in the case of SADLF, there are close links with leading non-government organizations and private seed companies.

[4] The Blackland research team has since left Texas A&M to work with the company "Mud Springs Geographers."

name a few of its salient features. The Atlas indeed allowed SADLF to refine the definitions of maize environments in the region. But the tool, plus training in its use, was also provided to more than 200 African researchers, and users now include personnel from other CGIAR centers (ICRISAT, ICRAF, and ILRI), private seed companies, and NGOs. Thus, the Atlas' impacts in research priority setting, regional collaboration, and effective targeting of new technologies go far beyond SADLF.

Regional Trials. To highlight differences between varietal performance under optimal management and farmers' conditions, a regional testing network was established among countries with stress screening sites. This network was consolidated with other regional testing efforts. Maize cultivars at the release and pre-release stages from public and private seed-producing entities are now routinely evaluated for tolerance to drought and N stress, as well as response under favorable conditions and resistance to several important diseases (all traits that affect a cultivar's performance under smallholder farmer conditions). Characterization for tolerance to acid soils and storage pests was also begun in 1999.

Interest in the trials has grown rapidly, and the number of trials has increased from 120 in 1996 to 395 in 2000. The trial network encompasses more than 50 collaborators and 30 institutions, and more than 150 elite, open pollinated varieties and hybrids from both private and public organizations are evaluated each year. Trial results are distributed to more than 300 institutions and individuals from the maize seed sector, and several national programs and non-governmental organizations (NGO) have begun using results to select entries for national maize variety trials and seed dissemination. Partial cost-recovery has been initiated through paid entries from the private seed sector.

Germplasm Products. Several cultivars already available in the region were identified as significantly higher yielding under drought and/or N stress, a characteristic not previously used to promote those cultivars. In addition, the project developed experimental maize genotypes that yielded 50% or more grain than popular check varieties or hybrids under levels of drought and N stress capable of reducing average yields to about 1-2 t/ha. One open-pollinated variety developed by the project—ZM521—has attracted particular attention. In 37 trials conducted throughout eastern and southern Africa, ZM521 yielded on average 34% more than current releases and showed impressive yield stability. In one set of trials where yields averaged only 1-2 t/ha (typical for smallholder farmers), ZM521 yielded 2.2 t/ha, surpassing local check cultivars by 50%. ZM521 is planted in on-farm trials across the SADC region, farmers and seed producers are greatly interested in it, and commercial seed production has begun.

In summary, SADLF has produced release-ready cultivars with 35-50% higher and much more stable yields for smallholder farmer conditions. The genotypes use water and nutrients more efficiently to produce grain, thus maintaining a relatively high harvest index (HI) under conditions that normally reduce HI to less than 0.2-0.3. In this sense, stress tolerant cultivars give smallholder farmers incentives for the first time to use improved management practices and to diversify crop production.

Moving SADLF On-farm. Having established infrastructure and partnerships and developed experimental, stress tolerant genotypes, the project then faced the challenge of systematically and cost-effectively verifying the performance and acceptance of new maize cultivars under farmers' conditions. To this end, SADLF adapted an approach pioneered for agronomy research by an ICRISAT researcher. Dubbed "Mother-Baby Trials," it involves sets of experiments grown in and by farming communities. For each researcher-managed "mother" trial, there are as many as 6 to 12 corresponding "baby" trials within bicycling or walking distance and managed entirely by farmers. The mother trial evaluates a set of promising maize cultivars under recommended and farmer-representative management conditions, thus demonstrating both differences between varieties and the effect of improved management practices. The mother trial is located in the center of a farming community, often at a secondary school, in the field of a progressive farmer, or at a research station. It is managed by a local counterpart, the agricultural teacher, an extension officer or an NGO staff. Baby trials contain a subset of the cultivars in the mother trial (no more than four) and are planted and managed exclusively by the farmers that host them. Because farmers want to use the information from the trials for purchasing seed of a good cultivar in the following year, only half of the entries are experimental; the remainder are recent releases already available on the market. Thus, adoption of newly released germplasm is taking place while research is conducted and decisions are made on future releases.

Performance data and farmers' opinions flow back to researchers and seed companies, increasing the chance that companies will provide the kind of seed that farmers really want. Through deliberate collaboration with a range of partners (NGOs, research stations, extension agencies, schools, farmers) and by providing valued information to seed companies, the system is expected to become self-sustainable after an initial start-up phase.

In 2000, 37 mother trials and more than 280 baby trialswer e piloted throughout Zimbabwe (Fig. 1). Collaborating partners included private seed companies; NGOs such as CARE International, SALRED (Southern African Unit for Local Resource Development), and ITDG (International Technology Development Group); community development associations, such as the Horseshoe Farmer Association in northern Zimbabwe, in which commercial farmers link with smallholders to improveagricultur e; the national extension service (AGRITEX); 15 secondary schools; and several national research stations. The trials involved not only individual farmers but entire communities through visits by neighbors, field days, oreven interactions between school children (who managed some mother trials) and their parents. In summary, the results have been useful for all and enthusiasm ishigh.

SADLF also collaborates with the CIMMYT-coordinated "Soil Fertility Management and Policy Network for Maize-based Farming Systems in Southern Africa" (Soil Fert Net), to test and target stress tolerant varieties. Funded by the Rockefeller Foundation, Soil Fert Net is working to improve the management of soil fertility resources in the maize-based smallholder farming systems of Malawi, Zambia, and Zimbabwe through effective, targeted research and extension, widespread partnerships, and appropriate policy support.

East, West and Central Africa

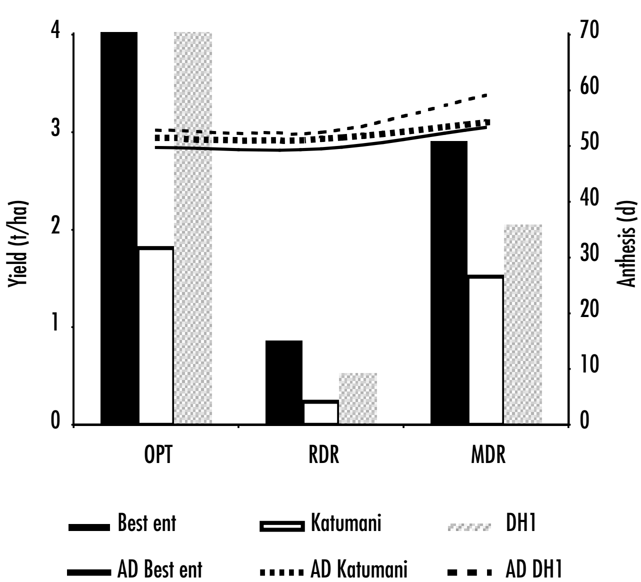
There is no question that the challenges to maize production in West, Central and East Africa are significant. However, technologies are available and in the pipeline that can significantly contribute to

Figure 1. Mother-baby trial sites in Zimbabwe, 2000.

addressing these challenges. CIMMYT and IITA have been collaborating with the national systems in the region for more than 20 years to develop higher yielding maize varieties adapted to the conditions of Africa's resource-poor farmers. Phase I of AMS entailed an intensive effort to incorporate stress tolerance into these varieties. From the beginning, this project was conceived of as a long-term effort, requiring 10-15 years to show full results in farmers' fields. The main focus in Phase I was on establishing the research infrastructure required for stress tolerance breeding. An expert review of Phase I conducted in February 2001, led by Drs. Duncan Spencer, Nyanguila Muleba and Fred Wangati, rated the project as one of the top three projects currently funded by UNDP worldwide. Among the most significant accomplishments of the AMS project in Phase I are the following:

Development of Research Infrastructure. The AMS has successfully established field experimental facilities that represent the major agro-ecological domains for maize production as delineated in the CIMMYT Maize Research Atlas. The screening and testing sites have been selected to coincide with the major maize stress factors of interest to the project and over 200 on-farm trial sites were selected around screening and testing sites in 9 countries. The AMS has contributed significantly to infrastructure and operations at these locations. A total of 19 sites to screen for AMS project stresses (six in West / Central and 13 in East Africa) and 126 testing sites (66 in West / Central Africa and 60 in East Africa) are now fully functional and under the direction of national systems, enabling African maize researchers to conduct stress breeding research for the first time. What is more, researchers received training in new breeding methodologies and all screening sites are fully computerized, so that the efficiency of research has been significantly increased.

Figure 2. Grain yield and days to anthesis of the best new stress tolerant population (Best ent.) compared to a commercial hybrid (DH 1) and the regionally popular OPV, Katumani, across seven environments representing optimal management (OPT), random drought and low soil nitrogen (RDR), and managed drought and low soil nitrogen (MDR), 1999A.



Increased Availability of Stress-tolerant Maize Germplasm. Although IITA and CIMMYT have been developing stress tolerant maize varieties for many years, the lack of screening and testing sites in the region prevented the incorporation of these materials into varietal pools evaluated and released by African countries. Under Phase I, more than 5,000 maize lines were systematically evaluated by project collaborators, and a number of materials with resistance to one or more key stresses have been found superior in yield towidely gr own varieties. Among these promising new materials are early and extra-early varieties that farmers prefer to Katumani, the single most popular "drought-avoiding" maize variety grown in East Africa. The breeding and screening approach used throughout the project guarantees that the new maizevarieties outperform curr ent commercial counterparts (varieties or hybrids) under stress conditions, while yielding at least as well under favorable conditions (Fig. 2). Thus farmers benefit from higher and more stable yields when conditionsar e difficult, with no yield penalty under good conditions.

Building Teams. AMS participants are proudest of the fact that, more than simply consolidating existing maize networks, the project has succeeded in creating high-quality research teams. Screening sites are being shared by national scientists across their respective regions. National systems are joining hands to lead research on particular stresses, with germplasm tested regionally and findings shared across national boundaries. National breeding programs are becoming more focused, with better planning and priority setting. Collaboration between CIMMYT and IITA is steadily increasing. Overall, the intangible but invaluable factors of trust and collegiality–without which collaboration is impossible–are clearly evident among the international centers, collaborating national systems, and the many researchers involved in the project across sub-Saharan Africa.

In short, Phase I of the AMS project has established a very solid foundation of physical infrastructure, research accomplishments, and human relationships. AMS participants work in multi-disciplinary teams, with extensive interactions among researchers from CIMMYT and IITA, national programs, extension workers, NGO staff, and farmers. Through extensive training activities under the project, CIMMYT and IITA have provided African scientists with tools to develop, test, and promote stress tolerant maize in their home countries. Moreover, capabilities and tools acquired through the AMS are being put to a range of non-project uses in the region, thus contributing to the emergence of modern agricultural research and development. This positions subsequent efforts to achieve accelerated impact, as new technologies (germplasm and complementary agronomic practices) are perfected and begin moving into farmers' fields.

Variety Improvement. CIMMYT-Mexico, CIMMYT-Zimbabwe (particularly SADLF), and the former CIMMYT program in Côte d'Ivoire have been the majorsour ces of stress tolerant maize used in the AMS project. CIMMYT-Mexico and CIMMYT-Zimbabwe have sufficient germplasm in the pipeline forthe AMS to upgrade varietal development continuously by broadening the genetic base of project germplasm. IITA and the national research systems have also contributed significantly to the range and diversity of germplasm used. Thus, more than 5,000 materials—exotic source populations, local materials, progenies, and various crosses—have been screened and tested in the region.

Project participants have effectively utilized this germplasm, as well as landraces and popular farmers varieties, in new stress tolerance breeding populations likely to produce good varieties for farmers. Germplasm is regrouped according to maturity and geographic adaptation. Selected genotypes are selfed, intercrossed, topcrossed and / or backcrossed repeatedly, as deemed necessary, to accumulate favorable genes through either simple recurrent or reciprocal selections. Genotypes are tested in network regional trials and on-farm trials (both researcher- and farmer-managed). The same genotypes are simultaneously screened under stress and unstressed conditions in different ecologies. This ensures selection of germplasm that is well buffered against environmental stress, a prerequisite for minimizing yield losses under farming conditions. Final release for use by farmers depends on stress tolerance, yield potential, and agronomic qualities. Products include high yielding varieties with good agronomic background, inbred lines for use in developing hybrids, and full vigor cultivars.

Secondary traits (anthesis-silking interval, tassel size, ears per plant, plant height, lodging resistance, stay-green or delayed leaf senescence, abcisic acid in leaves, root capacitance, leaf toughness) identified by CIMMYT and IITA as being associated with stress tolerance are used to speed selection and breeding. Because drought and low-N stress tolerances are quantitative traits under the control of several genes, gene markers obtained so far account for only 40 to 50% of total genetic variation.

Progress in mapping genes for Striga resistance may soon allow use of marker-assisted selection. Resistance to maize streak virus (MSV), an important disease endemic to sub-Saharan Africa, is also under control of quantitative genes, but these are clustered in a genome region sufficiently large to act as a single super-gene. Thus, DNA markers for MSV account for over 90% of genetic variation, and project participants are beginning work to use them in selection.

Evaluation for storage and grain quality characteristics is performed only at the farm level, but grain quality characteristics (color, flintiness, and others) are already incorporated into breeding populations.

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[5] Funded by the Canadian International Development Agency (CIDA), the EACP was initiated in 1985 to increase maize and wheat production and productivity in eastern Africa. Now in its fourth and final phase to end in 2002, the project is focused on enhancing the productivity, effectiveness, and efficiency of crop and natural resource management research and technology dissemination for maize- and wheat-based cropping systems in eastern Africa.

Agronomy and Cultural Practices. In East Africa, on-farm and on-station agronomic trials have been conducted mainly by national scientists and funded from competitive grants through the AMS or the East Africa Cereals Programme (EACP).[5] Experiments have focused on moisture stress management, especially through use of tied ridges, and nutrient management. Regional trials on strategies for addressing low soil fertility have been conducted in Ethiopia, Kenya, Tanzania and Uganda. Eleven potential legumes were tested for adaptation, establishment and seedling growth, growth rates and biomass accumulation, ability to fix N, and resistance to insects and diseases. Regional trials were also conducted on integrated nutrient management involving combined use of small amounts of high quality organic material with inorganic N.

In West and Central Africa, on-farm trials involved intercropping forage legumes with maize. Work often follows the WECAMAN practice that on-farm research teams comprise a breeder, an agronomist, and a socio-economist, and include economic analysis of the results.

From this considerable body of work, AMS participants are now attempting to identify, test, and promote "best bet" technologies adoptable by farmers in the short-to-medium term. In addition, participants will attempt to standardize experimental designs for on-farm trials, to facilitate comparative analysis across the region.

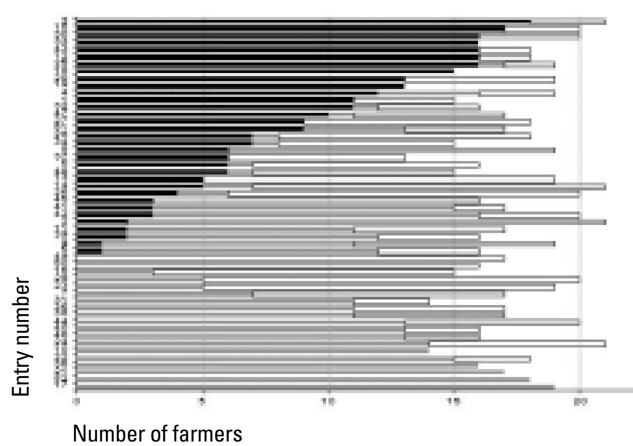
Farmer Participatory Approaches. Farmer participatory research in AMS has been mainly collaborative, with strong collegial elements. Participatory rural appraisal (PRA) has been used to elicit farmers' problems and understand their constraints. Participatory breeding and on-farm and mother-baby trials (a methodology acquired from SADLF) are being used to develop and test new technologies with farmers.

In eastern Kenya, PRAs were conducted in villages around each of four screening sites. Usually, separate group interviews were conducted for men and women concerning their preferences and selection criteria for maize varieties. An open-ended questionnaire and scoring scheme were used. For participatory breeding in Kenya, a set of farmers who participated in PRAswer e invited to each of four research stations toevaluate dif ferent varieties being tested at the screening sites and mother-baby trials were conducted(Fig. 3).

Farmers and scientists are making use of the results, obtaining information on the suitability of new cultivars for different agro-ecologies and their acceptability to farmers, who are pleased with the approach. Farmer participatory variety selection has also been institutionalized in West and CentralAfrica.

Seed Production. AMS has directly funded seed production and on-farm testing (often jointly with SADLF) in Burundi, Chad, Ethiopia, Guinea, Kenya, Senegal, and Tanzania. Project participants have collaborated in and backstopped maize seed production activities in national programs. Together, these activities account for the production of more than 300 tons of maize seed annually. However, as should be expected given the short time that development of new stress tolerant varieties has been underway, no new AMS varieties have entered the seed multiplication programs. The AMS is supporting the development of community based seed systems and small seed companies in many countries in the region and will allocate increased resources to this activity, as stress tolerant varieties and hybrids from its programs become available.

Figure 3. Participatory breeding under the AMS in 2000: farmer evaluation of 52 maize varieties one week before harvest (black = positive; grey = negative; white = neutral).



Strengthening National Research Systems. Courses and workshops have been organized on selection methodologies and for increasing farmer participation in breeding and on-farm testing. Topics and participants are chosen by national systems and approval by the WECAMAN and ECAMAW steering committees. The training provided, especially in computing to manage and evaluate large germplasm collections, has helped improve the capacity of regional scientists and technicians. Training events have also allowed researchers from different countries to establish friendships and professional ties, thereby fostering trust and the free exchange of information and germplasm. Frequent and extended contacts among researchers from the region and the CIMMYT and IITA teams has provided the former with access to high quality germplasm and methodologies, while allowing the international scientists to identify promising local technologies and genetic materials.

The project has facilitated expansion of WECAMAN membership from 8 to 11 countries, with the recruitment of the the maize research programs of Guinea, Senegal and Chad, and increased the network's eco-regional coverage from the Northern Guinea Savannah to all maize ecologies in the sub-region. In East Africa, the project has provided valuable continuity and opportunities for interaction and joint planning under ECAMAW. Finally, the AMS has helped strengthen linkages between ECAMAW and WECAMAN, improving the efficacy of maize research and development activities region-wide and laying the groundwork for eventual establishment of a pan-African organization.

Project Administration. The AMS is administered as a joint collaborative project between CIMMYT, IITA, and national research systems, with administrative duties and research direction shared between CIMMYT and IITA. The AMS is perhaps one of the best recent examples of fruitful collaboration between two CGIAR centers, and directors of participating national systems have confirmed their satisfaction with project management and operations. Collaboration with NGOs and extension services is developing steadily.

The Future

Chief among priorities for 2002 and beyond is securing sustainable funding for the AMS and SADLF. Firm support for the latter already exists in SDC and the Rockefeller Foundation. Given the favorable reviews of the AMS, several donor agencies have expressed interest in providing support. Assuming support continues, SADLF and the AMS will pursue the following:

- Mother-baby trials will be extended to other countries under both projects, and GIS-based site comparison studies will allow the projects to apply the approach more efficiently. The value of obtaining routine feedback to researchers and seed producers from the thousands of farmers participating is inestimable.
- As progress is made in breeding and release of higher yielding and better-adapted varieties, the main constraints to increased maize production in the region will be the lack of quality seed at affordable costs and the need for improved crop management practices. Both SADLF and the AMS are working to foster the establishment of effective community-based seed multiplication and marketing systems, and improved crop and soil management practices at the farm level.
- In breeding, efforts to use DNA markers will increase and the projects will focus as well on developing new, stress tolerant quality protein maize (QPM)[6] for sub-Saharan Africa as well as transferring the QPM trait to elite breeding and released materials already available for the region.

[6] QPM grain contains nearly twice the levels of two essential amino-acids, lysine and tryptophan, as normal maize, as well as a more balanced distribution of amino acids, significantly increasing its nutritive value. For more information, see "Quality Protein Maize: Improved Nutrition and Livelihoods for the Poor," p.27.

Research on Tropical Highland Maize

David Beck[*]

Introduction

The CIMMYT highland maize subprogram develops improved germplasm for the approximately 6.3 million ha of highland maize area in the developing world (Table 1). Almost half of this area is in Mexico; the remainder is in Central and South America, Africa, and Asia. Hard grain types predominate in Mexico, Asia and Africa. Floury and morocho[7] grain types are popular in South America (Table 2). White grain maize is preferred in 80% of the world's highland areas. This is because most highland maize is consumed directly as food by farmers and their families, and white grain is most suited for typical foods. Highland maize areas in developing countries can be classed into three broad, or "mega"-environments (Table 1).

Major abiotic constraints of highland maize include cold temperatures, frost, hail, and drought. Principal biotic constraints are *Puccinia sorghi* rust, *Exserohilum turcicum* leaf blight, and *Fusarium* ear and stalk rots. Insects usually are not a problem, although corn earworm can cause significant damage particularily in soft endosperm materials. The myriad of highland environments and the resulting genotype by environment (G x E) interactions, coupled with farmer requirements for grain texture, color, and size present significant challenges for breeding. At present in most highland environments, there is widespread use (nearly 90%) of local varieties.

The Mexican Highland Maize Farmer

A typical Mexican highland maize farmer lives in a high valley or plateau some 2,000-2,800 meters above sea level. He most likely farms ejido (communal) land, and has about 2-5 ha. His maize is of the Cónico or Chalqueño race type, characterized by purple and pubescent stems, high numbers of basal tillers under high soil fertilility conditions (few to none under typical farmer conditions), a very low tassel branch number (mainly Cónico), and ears with a high shelling percentage as a result of small cobs and deep grains.

About 80% of the arable land on his farm is planted to maize. Other crops grown are alfalfa, faba beans, phaseolus beans, and perhaps some cool season vegetables (broccoli, cabbage, carrots, etc.) and orchard crops (apples, peaches, pears, plums, etc., and highland avocado). He lives in a farming village, and travels to his plots each day. He usually has horses, mules, or burros which are used to transport him and his farming equipment to his fields. Plowing is usually done by tractor, but furrowing, planting, and cultivations are still commonly done using animal traction.

His maize is normally grown as a rainfed crop. If soil moisture permits, he normally plants deep (as deep as 25 cm) into residual moisture to get the maize crop

* CIMMYT maize breeder.

[7] Morocho grain is floury but has a hard outer cap.

Table 1. Highland maize mega-environments in developing countries.

Highland mega-environment	Location	Extension (million ha); [% world highland area]	Altitude range (meters above sea level)	Mean growing season temperatures (°C)
Tropical	0-30 ° N and S	3.3 [54%]	2,000-3,600	12-17
Transition	0-30 ° N and S	2.3 [38%]	1,500-2,000	17-20
Temperate	30-42 ° N and S	0.5 [8%]	1,200-2,500	15-20

started before the advent of reliable rains in June. Maize production here is mainly for home consumption. Farmers plant an intermediate-late white semi-dent type as the main crop, which has a growth cycle of 6-9 months. At higher elevations, they will also sow an early blue floury maize (6-7 months to maturity) nearby, or an early yellow or mixed color semi-dent maize in lower and dryer areas (5-6 months to maturity). In some high cool areas, farmers may plant a considerable amount of highland early white floury (Cacahuacintle) maize for home use and for marketing as fresh ears for sale or use in local dishes.

Maize fodder is an important commodity in many areas. At physiological maturity or just after the first frost, plants are cut at the base and tied into shucks. The objective is to produce forage with the maximum amount of tender leaves. Normally those who cut and shuck maize wait about one month before untying the shucks for harvesting of dried ears. All harvest is by hand, but machine harvest is feasible for the hard grained types.

Near major metropolitan zones, the dried husks have a high market value for use as wrappings for tamales (a maize food cooked and served in maize husks). This work is very labor intensive. Another specialty food made from highland maize is maize smut (a dish known as cuitlacoche, caused by the fungus *Ustilago maydis*). The fungus is considered a great delicacy and commands a high market price near large metropolitan areas. It is best if harvested when the smut galls are young and tender.

Table 2. Types of highland maize grown in the Andean zone, by grain texture.

Texture	Bolivia (000 ha)	Colombia	Ecuador	Perú	Total
White floury	45	10	10	67	132
Yellow floury	__	55	40	29	124
White morocho	15	50	20	__	85
Yellow morocho	65	150	10	41	266
Others	20	40	20	14	94
Total	145	305	100	151	701
	*(127	177	151	137	592)
% maize area	45	53	40	39	46

Source: Dr. Shivaji Pandey, CIMMYT, Cali, Colombia, April 1991.
* Data from Dr. Miguel Lopez-Pereira, CIMMYT Economics Program, 1990.

The Andean Highland Maize Farmer

A typical Andean highland maize farmer lives in a high, narrow, inter-Andean Valley some 2,200-3,200 meters above sea level. He is most likely farming private land, and has about 2 ha. He plants about 25% of his arable land to maize.

His maize is a floury or morocho type, characterized by non-tillering plants with often purple and pubescent stems, a high tassel branch number, and ears with extremely large kernels. The ears have 8 kernel rows, on average. Farmers often plant a high proportion of the maize land to floury maize for harvest and sale at the roasting ear stage. Dried floury grains are consumed as roasted, whole grains and morocho grain is consumed as mote. Harvesting and shelling are done by hand, since the very large and soft floury grain may be severely damaged by machine shelling.

Other crops include climbing beans intercropped with maize, lupines, quinoa, potatoes, cool season vegetables and orchard crops, and some wheat and / or barley. Maize is grown as a rainfed crop, but deep planting is not normally practiced. The planting season is from September to December. Full season varieties mature in 8-13 months.

CIMMYT Highland Maize Program

In the 1970s, the CIMMYT highland maize subprogram developed and improved 14 broad-based gene pools (4 floury, 4 morocho, and 6 semident) for the tropical highlands. During 1977-1986, CIMMYT worked with researchers in Ecuador to improve floury and morocho maizes. In the mid-1980s, the CIMMYT program shifted its attention to the hard-endosperm types that account for over 90% of the world's highland maize. This has remained its focus to the present.

Most unimproved highland maize has weak roots resulting in significant lodging, high numbers of basal tillers, low harvest index, and susceptibility to inbreeding. To make matters worse, genetic variability for these traits is lacking, so there is limited opportunity for improvement. To overcome these drawbacks, CIMMYT breeders adopted the strategy of assembling populations that included a portion of temperate and subtropical germplasm, to allow for more rapid improvement for agronomic traits. Backcrossing and recurrent selection were used to develop improved populations without losing favorable cold tolerance genes. Populations developed along with brief descriptions are listed in Table 3. These improved populations have demonstrated excellent performance (high yield, high harvest index, limited tillering, good roots, and tolerance to major foliar diseases) and are more tolerant to inbreeding, making them more useful for developing hybrids.

Table 3. CIMMYT headquarters populations for highland tropical and highland temperate areas.

Population	Code	Description	Primary target area
Highland early white semident.	Population 85	60% highland, 20% temperate, 20% subtropical/tropical germplasm.	Warmer highland areas[1].
Highland early yellow semident.	Population 86	55% highland, 25% temperate, 20% subtropical/tropical germplasm.	Warmer highland areas[1].
Highland late white semident.	Population 87	55% highland, 25% temperate, 20% subtropical/tropical germplasm.	Warmer highland areas[1].
Highland late yellow semident.	Population 88	55% highland, 25% temperate, 20% subtropical/tropical germplasm.	Warmer highland areas[1].
Highland early white floury.	Population 89	90% Cacahuacintle, 10% Andean races.	Highland areas[2].
Highland early white semident for very cold zones.	Population 900	Diverse highland germplasm	Colder highland areas[2].
Tepoztoctoc-1[3].	Population 901	Selections from Pool 10A and Pop 85.	Mexican highland areas[1].
Tepoztoctoc-2[3].	Population 920	Selections from Pool 11A, Pop 86 and New Zealand hybrids.	Mexican highland areas[1].
Tepoztoctoc-3[3].	Population 940	Selections from Pool 12A and Pop 87.	Mexican highland areas[1].
Tepoztoctoc-4[3].	Population 960	Selections from Pool 13A and Pop 88.	Mexican highland areas[1].
Temperate highland early white semident.	Population 800	Selections from Pops 85, 86, 87 and 88, New Zealand hybrids, elite Corn Belt Dent and northern European germplasm.	Himalayan region[4].
Temperate highland early yellow semident.	Population 845	Selections from Pops 86 and 88, New Zealand hybrids, elite Corn Belt Dent and northern European germplasm.	Himalayan region[4].
Tropical highland transition zone late white semident.	Pool 9A	Selections from Kitale synthetics, Ecuador 573, SR52, Tuxpeño de Altura.	Eastern and Southern Africa, Nepal, Americas.
Tropical highland transition zone late yellow semident.	Pool 9B	Same as Pool 9A plus Montaña from Colombia and Guatemala altiplano central selections.	Americas, Himalayan Region.

[1] Mean growing season temperatures of 15-17°C.
[2] Mean growing season temperatures of 12.5-15°C.
[3] For sowing up to 0.2 m deep.
[4] Mean growing season temperatures of 15-20°C.

Recurrent selection in most of the populations listed in Table 3 was completed in 1994. However, significant resources have been invested in pedigree breeding to develop inbred lines from these populations. Additionally, heterotic populations have been formed for the important, early-maturing, white semident group. Early generation inbred lines derived largely from Population 85 were recombined to form Population 902; lines from Population 800 were used to form Population 903. A smaller fraction of germplasm derived from Pool 10A, Population 901, and miscellaneous materials from the breeding nursery were also included in the recombinations. Populations 902 and 903 have been handled in an S_1 x tester recurrent selection scheme. Evaluations of drought and low N tolerance have been incorporated into selection. To date, inter-population heterosis is approximately 10%.

Inbred lines released by the highland program include seven early white and one early yellow linein 1993, and eight early white lines in 1997. Several lines have been used as parents in hybrids developed by the Mexican national program or seedcompanies. These pr oducts are the fruits of extensive and on-going collaboration between the CIMMYT highland maize subprogram and the Mexican public and private sector.

Research in 1999

As of 1999 (and continuing to present), the highland maize subprogram has increased its emphasis on the following:

- The development of early maturing yellow-grained heterotic populations.
- The development of elite QPM materials for the highlands.
- Line recycling in all germplasm types.
- Selection for drought and low N tolerance in our germplasm.
- In collaboration with the CIMMYT breeder in Ethiopia, enhanced linkages in the development of highland transition zone maize for Eastern Africa.
- Greater efforts in Mexico and all regions to help accelerate the adoption of improved OPVs and hybrids through training in seed production and consultation.
- Research in seed production.

Collaborative Research. The subprogram continued strong collaboration with Mexican institutions, including joint trial evaluations, exchange of germplasm, and visits and consulting, to name a few activities. The principal collaborating institutes include the National Institute of Forestry, Agriculture, and Livestock Research (INIFAP), the Institute of Agriculture, Livestock, Water, and Forestry Research

Table 4. Late yellow transition zone hybrids evaluated at two locations, Mexico, 1999.

Pedigree	Grain yield (t/ha)	Days to flower (Female)	Ear rot (%)	Moisture (%)	Ear aspect (1-5)*
POOL 9B C1 TSR 8P x POOL 9B C0 R.L. 71	13.9	96	10	20.8	1.4
POOL 9B C1 TSR 8P x A.T.Z.T.R.L. BA90 5	12.0	97	2	18.7	1.6
POOL 9B C1 TSR 12P x P.R.D.A.(2),S.M.L.,9A	11.0	91	14	17.1	1.4
CHECKS					
POOL 9B C1	5.4	94	24	21.2	2.6
ASPROS 910 / SB304	10.1	94	41	22.1	2.5
TROMBA	8.7	88	28	17.6	2.6
MEANS	8.6	94	20	20.2	2.3
C.V. %	16.0				

* 1 = excellent, 5 = poor.

and Training of the state of Mexico (ICAMEX), the Autonomous University of Chapingo, the Colegio de Postgraduados, the “Antonio Narro” Autonomous Agrarian University (UAAAN), and the seed companies ASPROS, ASGROW, and CERES. Most of these organizations have now released hybrids whose parents include one or more CIMMYT highland inbred lines. In general, there has been a significant increase in recent years in the use of CIMMYT highland maize germplasm by our partners.

Training. CIMMYT highland staff traveled to Zimbabwe, Kenya, Ethiopia, Guatemala, Trinidad, Ecuador, and Bolivia in 1999 to visit highland maize research and seed production efforts, help teach seed production courses, and strengthen collaboration.

Germplasm – Experimental Results. Late yellow-grained transition zone single-cross hybrids largely based on lines developed from Pool 9B were tested 1999 (Table 4). The best hybrid, POOL 9B C1 TSR 8P-2P-1P-2P-1P-3-B X POOL 9B C0 R.L. 71-2P-1P-2P-2P-1P-1P, yielded 13.9 t / ha across locations (37% higher than the best hybrid check and 157% above Pool 9B C1). Two others, POOL 9B C1 TSR 8P-2P-1P-2P-1-3-1 X A.T.Z.T.R.L. BA90 5-3-3P-1P-4P-2P-1-1 and POOL 9B C1 TSR 12P-2P-1P-1P-2P-2-B X P.R.D.A.(2), S.M.L.,9A)-1-1-1-1P-2P-2P, had excellent yields and agronomic characteristics. Standability, plant and ear aspect, and ear rot resistance were excellent in all these hybrids.

Table 5. Three-way cross hybrids with CIMMYT, ICAMEX and CERES germplasm (BA-9914A).

Pedigree	Grain yield (t/ha)	Male flowering (d)	Plant height (cm)	Stalk lodging (%)	Moisture (%)
(B16 x B17) x CML349	8.6	85.3	236	0.0	34.5
(CML244 x CML349) x R-838C	8.5	84.3	222	0.0	28.4
(CML239 x CML242) x IML-11	8.4	75.5	206	2.1	31.0
(CML239 x CML242) x IML-19	8.1	79.8	193	0.0	27.5
CHECKS					
CML244 x CML349	7.1	79.0	212	0.0	26.7
(CML244 x CML349) x IML-6	7.1	79.3	224	0.0	31.4

Table 6. Selected results from the CIMMYT Highland International Hybrid Trial (CHTH - 1999) across 27 environments.

Entry no.	Code	Pedigree	Grain yield (t/ha)	Days to silk (d)	Plant height (cm)	Stalk lodging (%)	Moisture (%)
1	CMS 959875	CML240 x IML-6	6.88	81	226	2.5	19.4
7	CMS 979075	P85C4 HCE 10-1-4-1-1 x CML349	6.59	77	237	1.8	18.9
16	CMS 939083	CML244 x CML349	6.58	78	236	1.2	19.8
15	CMT 9790235	(BPVC.BA90163 x P.800C5F37) x CML349	6.54	76	225	1.3	17.9
13	CMS 9790205	(P800C5F37 x BPVCBA90185) x CML349	6.47	76	236	2.5	18.0
2	CMS 9597293	BPVC.BA90 185-2-1-6-3-# x CML349	6.46	75	231	2.7	17.3
19	Local-check-1		6.96	87	242	4.6	20.3
20	Local-check-2		7.88	90	243	4.9	22.8
	Means		6.15	77	224	2.6	18.0

To exploit heterosis in a broader range of white-grained highland germplasm, we crossed some of the best CIMMYT maize lines (CMLs) and single-cross hybrids with lines and single-cross hybrids from ICAMEX, INIFAP-Aguascalientes, and CERES (Table 5). Over 200 crosses were produced at the CIMMYT experiment station in Tlaltizapán in 1999. Two trials of 110 entries each were formed and evaluated at El Batán under both low N and non-stressed conditions. Across two environments excellent yields were observed in various crosses between CIMMYT and INIFAP (B16, B17), CERES (R-838C), and ICAMEX (IML-11, IML-19) germplasm (Table 5). Particularly noteworthy was the three-way cross (CML239 x CML242) x IML-19, which had high yields, short stature, and low harvest moisture.

The CIMMYT Highland Trial Early / Intermediate Maturity White (CHTH) in 1999 comprised 20 highland, early / intermediate maturing, white-grained, single- and three-way cross hybrids. Although the two local checks ranked first and second for yield, they were significantly later in flowering and higher in harvest moisture than most of the CIMMYT hybrid entries (Table 6).

Table 7. The effects of different treatments on the synchronization of flowering and on grain yield in six highland maize genotypes, El Batán, 1999.

Pedigree	Grain yield (t/ha)	Change in male flowering (d)
Foliar application of N (1 or 2 dosis)	0.24	0.0
Foliar application of P (1 or 2 dosis)	-0.34	0.0
Foliar application of gibberelic acid	-0.51	0.2
Foliar application of micro-nutrients	-2.13	1.5
Planting depth (5-7 cm)	-0.06	1.8
Planting depth (5-10 cm)	-0.33	3.6
Plant density (33,000-67,000)	0.4	2.8
Flaming	-0.46	8.0
Cutting (4 leaf cut at ground level)	-3.21	13.7
Cutting (4 leaf removing half plant)	-0.53	3.5
Cutting (8 leaf removing half plant)	-2.63	3.8

Seed Production Research. Given that many farmers in developing countries do not replace their seed annually with newly purchased commercial seed, but rely instead on recycled seed saved from their own harvest or obtained from other farmers, we wanted to obtain estimates of yield reductions in different highland hybrid types. Thus, we evaluated inbreeding depression as a result of advancing various early-maturing highland hybrids from F_1 to F_2 and F_3. Two single-crosses, three three-way crosses, and two double-crosses were included in our study. The trial was evaluated in El Batán under both low N and non-stressed conditions. Trial mean yields averaged 11.6 and 4.1 t / ha under non-stressed and low N stressed conditions, respectively. Interestingly, similar levels of inbreeding depression were expressed under both conditions. Combined over the two environments, the single-cross hybrids demonstrated the highest inbreeding depression from the F_1 to F_2 generations (35.5 %), followed by three-way crosses (31.2%), and double crosses (14.9 %).

A second study[8] examined techniques for synchronizing flowering in hybrid maize production. The materials included three highland inbred lines and three single-cross hybrids. Techniques used either to delay or accelerate flowering included: 1) foliar fertilizer applications (N, P, gibberellic acid, micro-nutrients); 2) varying planting depth; 3) varying planting density; 4) cutting; and 5) flaming. Contrary to expectations, foliar fertilizer treatments did not hasten flowering (Table 7). Deeper planting delayed flowering 2-4 days, with minimal effects on grain yield. No significant differences were observed in flowering at the two plant densities tested. The cutting treatments significantly delayed flowering (from 3.5 to 14 days), but also stunted plants and reduced yields. Interestingly, the flaming treatment delayed flowering on average by 8 days with minimal negative effects on plant development or yield. With most of the techniques, the inbred lines were more affected by the treatments than the hybrids (data not shown).

[8] Part of the MSc program of CIMMYT research assistant, Jose Luis Torres.

Research in 2000

In addition to continued work on the research described previously, the highland maize subprogram expanded its efforts to include the following in 2000.

Crossing Highland, Transition Zone, and Subtropical Maize. To enhance heterosis and increase the yield stability of highland maize by broadening its adaptation, the subprogram began crossing elite, highland inbred lines with elite lines of transition zone and subtropical adaptation. Preliminary results suggest significant boosts in yield in numerous cross combinations (Table 8). In crosses between transition zone late white lines and highland late white lines evaluated at four locations, the transition zone line (TSRB(2)*9A)MZ2-3X-1P-1P-2P-1-1P-1P-1-1P-B-B in combination with three different highland late lines exceeded the yield of the best check hybrid by 13–16%. Most hybrids were shorter and earlier with less ear rot than the best check hybrid. Similar results were found in crosses between transition zone late yellow and highland late yellow lines (Table 9.). In this trial the top-yielding hybrids were 7–13% superior to the best check and had vastly better resistance to ear rot.

Table 8. Transition zone by highland white single cross hybrids evaluated in 4 locations, 2000.

Pedigree	Grain yield (t/ha)	% over best check	Plant height (cm)	Root lodging (%)	Ear rot (%)	Moisture (%)
(TSRB(2)*9A)MZ2-3X1P-1P-2P-1-1P-1P-1-1P-B-B X POB.87 C5 H.C.176-13-1-2-1-1-1-B-B	12.40	116	248	0.0	3.3	20.4
(TSRB(2)*9A)MZ2-3X1P-1P-2P-1-1P-1P-1-1P-B-B X B.T.V.C.H. BA92 1-B-1TL-1-1-3-B-B	12.02	113	239	1.1	4.1	23.3
(TSRB(2)*9A)MZ2-3X1P-1P-2P-1-1P-1P-1-1P-B-B X B.T.V.C.M. BA92 16-B-10TL-1-1-1-B-B	12.00	113	227	1.0	1.7	21.9
Best check (TROMBA)	10.65	-	244	3.8	7.2	23.5
Mean	10.60	-	243	0.8	4.0	22.6

Table 9. Hybrid single-crosses formed with yellow transition zone and late highland yellow lines, 2000.

Pedigree	Grain yield (t/ha)	% over best check	Plant height (cm)	Ear rot (%)	Moisture (%)
POOL9B C1 TSR-12P-2P-1P-1P-2P-2-B-B-B x S.MORADO TARDIO TL93A 5-B-1TL-1-1-1-B-B	14.27	113	278	6.1	26.7
POOL9B C1 TSR-12P-2P-1P-1P-2P-2-B-B-B x POB.88C0 HC 23-5-1-1-5-2-1-4-2-2-1-B-B	13.75	109	269	2.7	22.5
POOL9B C1 TSR-8P-2P-1P-2P-1-3-1-B-B x POB.88C5 HC 6-6-1-2-1-2-1-B	13.56	107	274	1.5	32.7
POOL9B C1 TSR-8P-2P-1P-2P-1-3-1-B-B x S.MORADO TARDIO TL93A 5-B-1TL-1-1-1-B-B	13.48	107	270	2.5	32.5
Best checks					
ASPROS-910	11.56	-	271	26.7	37.7
Niebla	11.62	-	273	19.0	29.5
Relampago	10.32	-	259	15.4	30.8
ASPROS-900	12.65	-	269	20.0	30.3
Mean	11.13	-	258	9.2	27.3

In a trial crossing lines from more divergent sources (in this case late highland white x subtropical testers) we found even higher levels of yield superiority over the best commercial hybrid checks. Table 10 shows results of single-cross hybrid combinations between highland late white lines and subtropical intermediate white testers. The best performing highland late line (Pob.87C5HC95-24-1-1-2-1-B-B-B) in crosses with the subtropical tester lines CML311 and CML384 exceeded the yield of the best check hybrid by 20 and 29%, respectively.

Added Germplasm Options for Partners. During 2000, the highland subprogram offered a greater range of trials through the international testing system. For the first time in our history, we supplied partners with a highland early yellow hybrid trial plus four advanced line trials. The line trials were grouped by maturity and grain color and included highland early white, highland early yellow, highland and transition zone late white, and highland and transition zone late yellow trials.

The Future

The subprogram is increasing research on yellow and quality protein maize (QPM), among others, in response to growing interest. This includes forming yellow grain, early-maturing, highland heterotic populations to complement the early-maturing, white heterotic populations already formed. Line recycling is receiving increased emphasis, including work to convert highland CIMMYT maize lines (CMLs) to QPM. Further studies on the physiology of highland maize, along with better classifications of highland environments through use of geographic information systems and other techniques, are needed to improve our understanding of G x E and to develop more efficient breeding strategies. With the placement of a CIMMYT breeder in Ethiopia, links are being strengthened to develop useful varieties for

Table 10. Hybrids based on highland late white by subtropical tester lines, 2000.

Pedigree	Grain yield (t/ha)	% best check	Days to male flowering	Plant height (cm)	Stalk lodging (%)	Ear rot (%)	Moisture (%)	Plant aspect (1-5)	Ear aspect (1-5)*
B.T.V.C.M. BA92 16-B-10TL-1-1-1-B-B x CML-311	13.74	126	86.3	216	0.0	6.0	26.7	2.5	2.5
POB.87 C5 HC 95-24-1-1-2-1-B-B-B x CML-311	13.57	124	86.0	238	2.0	5.4	25.5	2.5	1.8
B.T.V.C.M. BA92 23-B-1TL-1-2-1-B-B x CML-311	13.52	124	86.0	241	0.0	5.4	32.2	2.4	1.8
POB.87 C5 HC 95-24-1-1-2-1-B-B-B x CML-384	13.48	123	91.3	241	2.0	2.4	25.1	2.4	2.0
Checks									
CML-311 x CML-384	10.93	-	99.0	225	0.0	7.5	31.4	2.5	2.4
Tromba	10.72	-	90.3	229	0.0	4.4	22.9	2.4	2.6
Halcon	10.55	-	79.3	214	5.9	3.6	16.1	2.8	2.8
Mean	11.97	-	89.6	224	1.7	6.1	26.0	2.5	2.4

* 1 = good; 5 = poor.

highland transition zones in eastern Africa. Greater efforts in seed production training and consulting in Mexico and other regions will help accelerate adoption of improved OPVs and hybrids.

By Spring 2002 we plan to release approximately 10lines adapted to either highland or transition zones and having early or late maturity and white or yellow grain type (Table 11). We also will have available about 27 new synthetic varieties with similar combinations of adaptation, maturity and grain color (Table 12). The newly released highland synthetics and inbred lines in hybrid combinations will be further evaluated in a series of international hybrid trials to be made available in March, 2002 (Table 13).

Table 11. Highland program lines scheduled for release in Spring, 2002.

Category	# of Lines
Highland Early White	2
Highland Late White	3
Highland Late Yellow	3
Transition Zone Late White	2
Total	38

Table 12. Highland program synthetics available in Spring, 2002.

Category	# of Synthetics
Highland Early White	7
Highland Early Yellow	4
Highland Late White	4
Highland Late Yellow	4
Transition Zone Late White	4
Transition Zone Late Yellow	4
Total	27

Table 13. CIMMYT International maize trials - highland ecologies, 2002

Trial name	Trial description	Maturity	Grain color	Entries
	VARIETAL TRIALS			
EVT17 EW	Highland early white variety trial	Early	White, Yellow	30
EVT17 IWY	Highland interm.-late white & yellow variety trial	Interm.	White, Yellow	9
EVT17 TLWY	Transition zone late white & yellow variety trial	Late	White, Yellow	9
	HYBRID TRIALS			
CHTH-HEW	Highland early white hybrid trial	Early	White	20
CHTH-HEY	Highland early yellow hybrid trial	Early	Yellow	12
CHTH-HIW	Highland interm.-late white hybrid trial	Interm.	White	15
CHTH-HIY	Highland interm.-late yellow hybrid trial	Interm.	Yellow	12
CHTH-TZLW	Transition zone late white hybrid trial	Late	White	15

Increasing the Productivity and Sustainability of Maize-Based Cropping Systems in the Hills of Nepal

Joel K. Ransom, Neeranjan Rajbhandari ***

Summary of Accomplishments

In 1999 CIMMYT began work with partners in Nepal to develop and deploy productivity-enhancing, resource-conserving maize technologies appropriate for farmers' circumstances and the fragile hill environments of Nepal. With funding from the Swiss Agency for Development and Cooperation (SDC), participants in this effort are identifying, testing, and promoting promising technologies, especially improved seed and agronomic practices, evaluating adoption and constraints to adoption, and providing training for national researchers, extension workers, farmers, and other collaborators. The project focuses its activities at four hill research stations, with seed production and technical support being provided by Nepal's National Maize Research Program, located inthe lowlands.

The Hill Maize Research Project (HMRP) has now completed its second year. Among its accomplishments are a working version of the GIS-based Maize Almanac for Nepal, developed under the leadership of the CIMMYT Natural Resource Group's GIS and Modeling Lab. The Almanac has been distributed widely and demonstrated to maize scientists as well as to the broader research and development community within Nepal. The fieldwork of the project's baseline survey was completed in May and the synthesis report of the rapid rural assessments conducted in 1999 has been published. Planning meetings that focused on soil fertility and post harvest research aided in the development of research programs for 2001. A range of trials involving local and internationally developed improved varieties was planted at each of the hill research stations and/or associated outreach sites. Breeders' seed of 13 released or pipeline genotypes and foundation seed of 8 genotypes was produced. Eight crop management experiments were conducted at one or more locations. Community groups at 7 locations produced more than 13 tons of certified seed. Three in-country training courses, "Using the Maize Almanac," "Trainer's Training on Seed Production," and "Using Computers to Analyze Data," were held during the year. Four scientists participated in training courses outside Nepal. The following sections describe in greater detail the importance of maize in Nepal and advances and directions in the HMRP.

Maize in Nepal

Maize is the second most important staple food crop after rice in Nepal. Furthermore, the importance of maize in Nepal has increased substantially in the past 30 years with maize area and production nearly doubling (Fig. 1). The crop is currently grown on some 800,000 ha with an average yield of 1.8 tons t/ha. Maize is used primarily for human food, but is increasingly important as an ingredient in animal feeds, particularly where good roads and market access exist. Maize stover is also an important source of fodder for livestock in mixed animal-crop farming systems where maize is grown.

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Maize is produced in three rather distinct agro-climatic zones within Nepal: the Terai and inner-Terai (below 600 m), the mid-hills (600-1,800 m), and the high-hills (above 1,800 m). The greatest area of production (70%) is in the mid-hills, followed by the Terai (22%) and the high-hills (8%). Although maize area and production have grown substantially over the past 30 years, maize yields have been more or less static. According to estimates, during the next two decades the overall demand for maize in Nepal will grow by 6-8% per annum, largely as a result of the increased demand for food in the hills as population increases, and for livestock feed in accessible areas in the Terai and inner-Terai as the demand for milk, meat and meat products grows. Future production increases must come from increased productivity in maize-based systems, as there is little opportunity for further expansion of cultivated area, especially in the hills. Nepal's policymakers and research directors have given high priority to the development of agriculture in the hills, and an increase in maize yield per unit land area is an essential component of this.

Maize in the Mid-hills

Maize occupies about 80% of the cultivated land in the mid-hills and is the major source of calories, an important source of protein, and pivotal to family survival and the well-being of some 10 million hill dwellers. In the upper hills it is perhaps the third most important crop, occupying about 30% of the cultivated land. Maize is often grown in intercrop or relay with millet, soybean, cowpea, and potato. From west to east two agroecological zones can be identified in the hills, each depending upon the monsoon rainfall pattern and moisture regime:

The Western Dry Zone. This accounts for about 20% of the maize in the mid-hills. Low rainfall and a late and short duration monsoon characterize this environment. The maize crop is established on quite reliable pre-monsoon showers. The growing season is short, prone to drought and the usual practice is monocropping of maize. Some winter rainfall allows for crop production in the winter. Summer monocropped maize on rainfed terraces, followed by wheat / or other winter crops, iscommon.

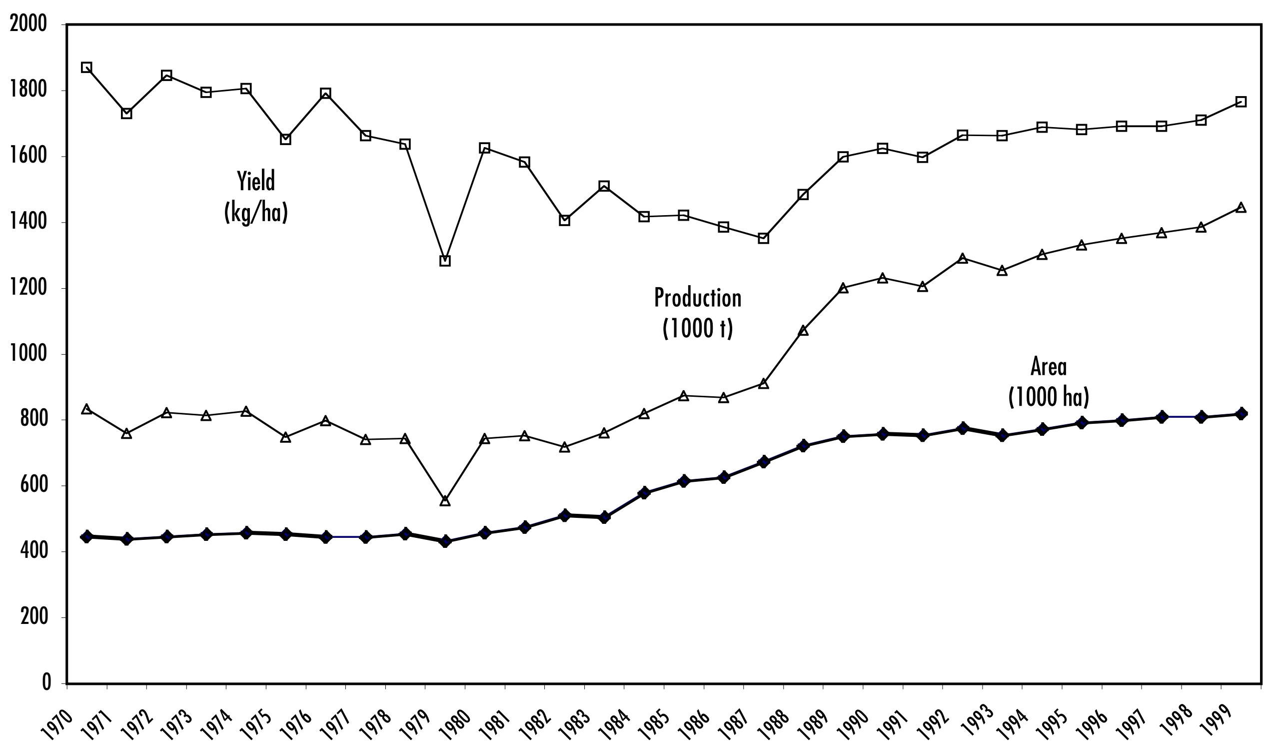


Figure 1. Maize area, production and yield over the period 1970-1999.

Eastern and Central Wet Zone. This accounts for about 80% of the maize in the mid-hills. The area is relatively wet due to high rainfall with longer duration of monsoon rainfall, but has relatively poorer pre-monsoon showers and almost no winter rainfall. The major cropping pattern is a summer maize relayed / intercropped system with millet or legumes. In the lower elevations where irrigation is available spring monocropped maize on irrigated terraces followed by rice is common.

In the mid-hills monocropped early-maturing maize is sown in March, harvested in August and followed by a crop of wheat or mustard. In the higher hills late-maturing maize is sown during April and often relayed with millets or intercropped with legumes. Harvest occurs in October, or later in the higher areas because of the cooler temperatures. Maize-based cropping systems are dual purpose: they provide both grain and fodder, the latter as green thinnings between emergence and flowering, or as mature plant stover following harvest. Crop residues are thus fully utilized either as fodder or compost, and none except roots are returned to the soil. Though average maize yields are low, they disguise a large variation in yield among fields; some innovative hill farmers are consistently producing maize yields as much as three times the national average.

Mid-hill Productivity Constraints. The mid- and upper hills of Nepal are generally food deficit areas, and additional food must be imported from the Terai by road or carried by porter for several days. Environmental deterioration is one result, as families intensify cropping or expand farming into new and fragile lands to meet their needs. Also common is outmigration to already crowded urban areas, where new arrivals usually add to the ranks of the destitute. Because many men work off-farm, many of the day-to-day on-farm decisions are taken by women. These include varietal and seed selection and the timing and nature of management operations. Decisions related to intercropping for households needs, for example, are often taken by women. Goat herding also plays a special role in the economic independence of women, since goats are used as dowry and remain the property of women after marriage. Thus, factors which relate to the nutrition of the family and household livestock (such as maize for fodder) may directly affect women's status.

Yields fluctuate seasonally in the hills, but have begun to decline. This reflects among other things the expansion of maize into less suitable terrain, an increased intensity of cropping and soil erosion, and the low utilization of improved varieties. Traditional fallows have all but disappeared. Reduced access of cattle and people to forests and the increasing demand for animal fodder have reduced the amount and quality of compost, accelerating a decline in soil organic matter and fertility and increasing the mining of nutrients in even better endowed hill areas.

Although farmyard manure (FYM) is widely used on maize, its availability has not kept pace with requirements. One important ingredient of FYM is leaves from the forest, and as the forest area has declined or community projects have restricted access to forest lands, so the volume of FYM has declined. Deficiencies of N and to a lesser extent P and micronutrients are increasingly common. Research is greatly needed on resource management in rainfed upland areas, especially in relation to terrace margin management with alley crops such as forage shrubs and trees, as it affects nutrient renewal (through N fixation) and the livestock (feed) components of the nutrient cycle.

Little chemical fertilizer has been utilized in the hills in the past, and when used it was applied relatively more to wheat and rice. A growing trend in areas with some road access is the use of urea as a topdressing to maize four to six weeks after emergence. Farmers often apply and incorporate around 25 kg N / ha in this manner, usually during weeding and just before transplanting finger millet. There is further evidence of growing labor and land shortages in the hills and the drudgery associated with the transport of bulky FYM (less than 2% N) to high hill terraces. Fertilizer is subsidized (1 bag of urea costs around US$ 6.50 at depots in the hills), knowledge about the short-term benefits of fertilizer is becoming widespread, and its usage seems here to stay, despite reservations in the minds of many about its overall effects on soil quality.

Fertility levels also vary considerably within specific fields. Experience suggests that a maize variety grown on terraces, such as those encountered in Nepal, will experience levels of available N that vary from near zero on the inner margins of the terrace where compost may not have been applied or where infertile subsoil has been exposed, to 120 - 150 kg N / ha where manure piles have been dumped prior to spreading, where urea has been unevenly applied, or where soils are naturally deeper and more fertile.

Although use of modern maize varieties and hybrids is fairly widespread in the terai, adoption has been much lower in the hills. To begin with, there is a shortage of varieties suited to mid-hill conditions and requirements, so farmers continue to grow the same maize varieties year after year. Over time these become "contaminated improved" varieties with possibly inferior production characteristics. In addition, farmers sometimes prefer local varieties over improved ones for reasons unrelated to grain yield (e.g.; taste, early maturity, fodder yield, quality husk cover, tolerance to field and storage pests, early maturity). Storability is also a key factor: most farmers keep maize as fully husked ears in outdoor storage structures called Sulis or Thangros.

Aside from issues of adaptation, the lack of quality seedr emains a major constraint to adoption in the hill country; access to improved seed varies from generally poor to non-existent. Problems in seed multiplication, delivery and production at the community level are the major bottlenecks and should be addressed through community-based seed production programs. As well, most farmers do not seem to think that processed, improved seed is worth the investment, and it remains achallenge to demonstrate its worth under their production conditions.

Efforts to increase the productivity of Nepal's maize-based systems must thus include the introduction of both new adapted varieties and improved crop management techniques to address the decline in soil fertility and other natural resource constraints. Under the present circumstances the scope seems limited to increase the productivity of maize-based system in uplands and in the more remote hill areas through increased use of external inputs, with the possible exception of improved seeds, though this may also be changing as roads continue to be built.

The Hill Maize Research Project

Several maize-oriented projects have addressed production issues in the past, but most focused on the terai and inner terai regions. The HMRP began in Nepal in January 1999 to increase the food security of farm families in hill areas by raising the productivity and sustainability of maize-based cropping systems. To accomplish this, work focuses on the following:

- Developing and promoting 1) improved maize varieties adapted to hill environments, and 2) resource-conserving, productivity-enhancing crop management practices for maize-based systems, appropriate to farmers' circumstances and compatible with existing cropping and livestock systems.
- Reducing crop losses from drought, low fertility, diseases and pests (including post-harvest insects and ear rots) through focused breeding efforts and integrated pest management approaches (mainly host plant resistance).
- Strengthening the research capacity of the National Maize Research Program (NMRP), the National Agricultural Research Council (NARC) Agricultural Research Stations, and allied institutions, with special attention to linkages between technology generation / verification and its delivery to farmers.

There is a wide range of partners or potential partners. The NMRP has the national mandate for maize research and improvement and operates its research and source seed multiplication program through the network of NARC research stations nationwide. Maize research in the hills is concentrated at the Lumle, Pakhribas, Kabre, Khumaltar, and Dailekh Agricultural Research Stations. Each station also has a command area of several districts where on-farm research is conducted. The Department of Agriculture has an agricultural development office in each district, and there are some 55 districts in the hill areas of Nepal. These in turn are supported by a network of agricultural supply centers and sub-centers managed by extension agents. The DOA also manages a network of farms to produce seed and planting materials in collaboration with NARC, and its products are delivered to farmers through the Agricultural Inputs Corporation (AIC), a parastatal input-distribution organization that focuses mainly on fertilizers. Finally, there are around 5,000 non-governmental organizations (NGOs) operating in the hills of Nepal. Most have strong community-level connections, and while some are opposed to the use of improved production technologies, there are others who are searching for new ways of increasing community wealth and sustainability. Less than 20 of these are operating in across-zone activities in agriculture; several are international andothers have activities in many ar eas of Nepal (examples include the Tuki Associations, Potato Seed Producers Groups, KOSIPAN, CEAPRED, CARE Int., Lutheran World Services, and World Neighbours).

1999 Results: Laying the Groundwork. During 1999 the essential operational procedures and committees were established and staff recruited. A beta version of a maize almanac, which will allow NARC staff to identify areas of common agro-ecology, was developed and demonstrated to NARC scientists. Rapid rural assessments were conducted throughout the hills and priority research constraints and important characteristics required by farmers in new varieties were identified. A questionnaire for a baseline survey was developed and teams identified for its application. Twenty-seven germplasm evaluation trials containing exotic material from CIMMYT Mexico and Zimbabwe were successfully carried out at five research stations and on adjacent farms. Several genotypes were found to be well adapted with high yield potential and were selected for further testing and improvement.

Protocols for the development of community based seed production were designed and plans advanced for seed production at sites near the four main hill research stations. A document summarizing guidelines for streamlining the development, testing, maintenance and seed production of maize varieties was drafted.

The number of activities implemented by the project increased significantly in 2000, as more scientists became involved, and technical aspects received fuller attention.

2000: Technical Activities in Full Swing. In the hills of Nepal, maize is planted with pre-monsoon rains, which arrived in early March this year. Most research activities supported by the HMRP followed soon after. Rainfall was above average (more than 6,000 mm of rainfall was received at Lumle), which intensified disease pressure and increased the incidence of waterlogging in poorly drained fields. Maize production and yield on a countrywide basis, however, was greater in 2000 (1.48 million tons; average 1.8 t/ha) than in 1999 (1.45 million tons; average 1.77 t/ha). Maoist activities intensified within Nepal and are particularly problematic to the project at two key sites, Kabre and Dailekh. Basic grain prices fell sharply because of the excellent rice crop harvested in Nepal and in India. Although the price of maize is not a significant concern for farmers who consume all that they produce, the low price is a significant disincentive to maize producers who market some or all of their produce.

Improved Targeting: The Nepal Maize Almanac. A working version of the GIS-based Maize Almanac for Nepal was developed in 1999 and early 2000 under the leadership of the GIS lab in CIMMYT-Mexico. The Almanac, which includes both software and databases, was released by CIMMYT in February. At that time most of the scientists involved in HMRP activities and other key research managers were exposed to the potential uses of this tool and were trained in its use. The Minister of Agriculture enthusiastically participated in one of the training sessions. Approximately 50 copies of the Almanac were distributed on CDs. Additional data are being sought to enhance the precision of the Almanac outputs. As new data become available, they will be incorporated into the existing databases and updated CDs will be distributed. Among other things, the Almanac was used to refine definitions of the major maize growing ecologies of Nepal.

Socio-economic Surveys. A synthesis report from the Rapid Rural Assessments (RRAs) conducted in 1999 was published. The RRAs were carried out at 46 sites, which allowed for the first compilation of data on socioeconomic, biological, and physical factors affecting the production of maize across the entire country. Data from these RRA clearly demonstrated the need to shift research resources from the Terai to the mid-hills, where most of the maize in the country is grown and where it dominates the farming system. They also helped to better define the environment in western Nepal. Previously, western Nepal was thought to be a dry zone requiring early maturing types. Closer analysis has revealed that, although this region is dryer than most areas of central and eastern Nepal, rainfall is sufficient to allow the cultivation of high yielding full-season genotypes. The lack of adoption of adapted high yielding varieties is partially explained by the fact that farmer in western Nepal prefer maize varieties with a floury grain-type suitable for making roti, a maize bread that is the chief way inhabitants consume maize. Farmers in this region also require access to early genotypes, because most farmers do not have enough stored maize to carry them to the end of the normal growing season. Furthermore, reliable winter rainfall in western Nepal allows for the cropping of wheat after maize. These new insights have helped direct the research towards developing genotypes that are more productive and useful to farmers and towards addressing the needs of the more intensive maize-wheat system. Little research had been directed toward this cropping area in the past.

Socioeconomic data from these surveys showed that little maize is actually sold to the formal market from the hills; thus, maize farming generates little cash for the household. Nevertheless, in addition to being the primary source of food in most households, it is used extensively to pay hired labor and for bartering in the local markets. Interestingly, the RRAs revealed that the use of urea is expanding, even in the more remote areas of the country. This information has promoted additional research on how to balance the nutrients being supplied from both organic and inorganic sources.

Starting from the maize ecologies defined using the Almanac and data from the RRAs and baseline survey, major biophysical and socioeconomic constraints to maize production were identified. Applying a methodology recently developed for use in establishing global priorities for CIMMYT's maize program, constraints were ranked according to efficiency, poverty, subsistence and combined indices. The data clearly indicate that the mid-hills of the Western, Central and Eastern Development regions require the greater emphasis and identified two constraints—white grubs and low plant populations—currently not addressed under the HMRP, but for which activities will be established in2001.

Monitoring Innovative Farmers. Staff at the four hill research stations attempted to find and monitor innovative farmers. This was the first time that NARC scientists had undertaken this type of activity. This year's work did not reveal any innovations that were considered sufficiently promising to require further evaluation in experiments. Initial findings that need additional monitoring and clarification as to whether they are indeed innovations and are practical for wider implementation include:

- Early planting (10-15 days earlier than was traditionally practiced) can produce higher yields.
- Applying manure in the winter rather than waiting until the spring improves yield.
- Stacking maize stover and keeping it for 4 or 5 months improves its palatability.
- Use of *Acornus* calamus roots and *Xanthoxylum armatum* and *Artemisia vulgaris* leaves helps reduce weevil damage in stored grain.

Soil Fertility and Post-Harvest Management. Working group meetings on soil fertility and post-harvest management were held to better understand and document the research that has already been carried out and to agree upon a strategy for addressing these priorities within the project. As a result of the soil fertility meeting, the HMRP now focuses soil fertility research efforts on improving thequality of or ganic materials applied by farmers, developing more rigorous system-based fertilizer recommendations, developing recommendations thatwill allow for the incr eased inclusion of legumes or high value crops in the system, and devising methodologies that reduce losses of soil from erosion. Furthermore, post-harvest research by HMRP participants now concentrates on 1) developing new storage structures or modifying existing ones to allow for more rapid drying after harvest, 2) screening new varieties more rigorously for resistance to post-harvest insect infestations and damage, and 3) more carefully evaluating the economics of biopesticides and insecticides for the control of post-harvest insects. Additionally more detailed information on post-harvest losses and on grain use profiles has beeninitiated.

Seed Production. Breeder's seed of the following materials was produced at one or more of the Hill research stations: Arun-1, Arun-2, BA 93, Ganesh-1, Ganesh-2, Manakamana-1, Hill Pool Yellow, Hill Pool White, Kakani Yellow, Madi White, Pool 21, Population 22 and Rampur Composite. Foundation seed of the following materials was also produced at one of more of the hill stations: Arun-1, Arun-2, Ganesh-1, Ganesh-2, Manakamana-1, Hill Pool Yellow, Hill Pool White and Rampur Composite. The seed multiplication program was better coordinated in 2000 than in 1999, so that the amount of land at the experiment stations in the hills used for seed production was reduced. Furthermore, earlier plantings this year at Rampur will enable the HMRP to supply most of the entries to be included in 2001 trials from local sources.

Genotypes being produced in 2000/2001 at Rampur for use in the 2001 summer season include: Across 94502, Tlaltizapan 9542, Across 9433, Across 9244, Harare 94502, Across 94501, Udipur 9433, Pop 45, Pop 42, Pop 44, Tlaltizapan 9544, Upahar, Narayani, Manakamana-1, Manakamana-2, Hill Pool White, Hill Pool Yellow, Across 9331, ZM621, SNSYN F1 (CGA-A/B-9), ZM601, DRACON SYN F1/DRBCO SYN F1, [P501-SRC0-F1/P502-SRC0]-F1, ZM521, ZM421, SZ SYNKIT II/SZSYNECU573, [AC 969-A-SR(Best FS0] F1-#, KIT/SNSYN[N3/(UX)]C1-F1-#, ECU/SNSYN[SC/ETO]C1-F1-#, SUWAN-3, SUWAN-5.

Germplasm Testing. Eight observation trials were grown in 2000, consisting of four experimental variety or hybrid trials from CIMMYT-Mexico, two from CIMMYT-Harare, inbred lines from CIMMYT-Thailand and F_1 crosses generated at Rampur. From these trials the following materials were selected and will be evaluated in the Intermediate Yield Trial (IYT) in 2001: Celaya-9733, Celaya-9745, Pantanagar-9745, Bangalore-9745, Across-9745, Sids-9445, Tlaltizapan-9542, Across Mexico-97501, Across-97501 and Across-94501.

The Intermediate Yield Trial was grown at four locations in the hills. Based on the results of these trials, the following genotypes were selected and will be advanced for testing in the Coordinated Variety Trial (CVT) in 2001: P501-SRC0-F1, DRACONSYNF1/DRBC0, ZM601, ZM521, ZM421 and GRACE (EWI-2). The CVT was grown in five locations, two by Lumle and one each bythe other hill stations. The following genotypes out-yielded the standard checks and were selected for inclusion in the Farmer Field Trials (FFTs) in 2001: ZM621, Hill Pool Yellow, Hill Pool White and LATAC1F1/LATBC1F1. ZM621 was particularly high yielding, producing 34% greater yield than the average yield of the checks. It is interesting to note that the material from CIMMYT-Zimbabwe is consistently doing well in the mid-hills of Nepal and that three promising genotypes that are being advanced in the testing system were developed with input from the SDC-funded projectat CIMMYT-Zimbabwe.

Farmer field trials were grown in farmers' fields under the supervision of staff from each of the four hill research stations. Because of the large variation within these trials and the small number of locations where they were grown, there were no statistically significant differences between varieties across sites. Nevertheless, based on farmer feedback, Population-22 was the preferred entry at most sites. Data on Population-22 will be compiled and submitted to the varietal release committee in 2001, and it may also be included in some limited on-farm seed multiplication in 2001, if sufficient foundation seed is available.

Improved Crop Management Practices. The followingcr op management research trials were conducted in 2000:

- Determining limiting nutrients (all hill research stations).
- Synchronizing crop requirements for N with inputs from organic and inorganic sources (all Hill research stations).
- Optimizing the productivity of the maize/wheat system in western Nepal (Dailekh).
- Optimizing maize soybean intercropping (Duerali, Lumle's outreach site).
- Crop rotation and diversification to improve soil fertility and productivity (Lumle).
- Optimizing maize and millet intercropping (varietal

combinations, direct seeding millet comparing maize sole to the system) (Kabre).

- Evaluation of different legumes for intercropping with maize–soybean, cowpea and beans (Pakhribas).
- Identifying a suitable scheme of planting legume intercrops with maize-optimum ratio and density of intercrop components (Pakhribas).

The major findings include the following:

- The soybean variety CN-60 grows well as an intercrop with maize. The combination of maize intercropped with CN-60 produces returns superior to other intercrops and may be a viable option for extensive areas that are currently growing maize-millet combinations.
- Confirmation of the very important role that organic inputs have on sustaining of the productivity of maize-based systems in the hills of Nepal.
- Greater overall productivity is achieved with intercropping; selecting intercrop varieties and speciesthat ar e adapted to the heavy rains during themonsoons is a key ar ea for further research.
- Improvement in the management of trials, particularly those conducted on-farm, is needed at most sites to generate reliable data and develop effective recommendations. Much of the training in 2001 will focus on improving trial and data management.

Improved technology dissemination. Farmer fieldtrials wer e planted on-farm in outreach sites associated with each Hill ARS. Diamond trials were planted at Dailekh and Kabre to demonstrate the effectof impr oved soil fertility and varieties on yield.Inaddition, the “Limiting Nutrient” and “Synchronizing N Requirement” trials described above were planted on-farm, though the intent of these trials was more towards gathering data to enableef fective recommendations, rather than on thedemonstration ofa new technology per se. The soybean-maize intercropping research at Duerali, an outreach site of Lumle, generated a great deal of interest within the community where it was grown. Many farmers requested seed of CN-60. This work will be expanded tomor e sites in 2001.

Community Seed Production. The lack of of good quality seed constrains the adoption of improved genotypes in the hills of Nepal. Given the inaccessibility of most villages in the hills, conventional methods of supplying improved seeds are ineffective. The project is, therefore, supporting the production of seed at the community level. Seven farmer groups under the supervision of the four hill research stations successfully carried out community-based seed production. In total, 13.7 t of seed of three varieties was produced. A total of 99 farmers were involved in these seed production activities. In addition to providing foundation seed of the varieties to be multiplied, HMRP provided technical support to farmers producing seed, with limited advice on issues related to group formation and marketing. There are concerns that at some sites the seed producers will not be able to sell all that they produce. Some emphasis on assisting producers in linking with others involved in marketing seed should be provided next year. It is recommended that the program be expanded into new areas next year, but technical advice to groups that produced seed in 1999 should be continued if required. Given the poor market linkages between villages in the hills, the project will strive to support a large number of relatively small production enterprises so that seed will be more readily available to more farmers. To the extent possible, the HMRP will conduct on-farm demonstrations involving varieties multiplied in a givencommunity .

Training. Three in-country training workshops wereheld:

- Utilizing the Maize Almanac. Thirty-one researchers and administrators from within NARC, MOA and a few NGOs attended a two day training course (28-29Febr uary) and approximately 20 senior administrators from within NARC and the MOA (including the Minister) attended a one day overview workshop (1 March) on the use of the Maize Almanac.
- Training Trainers of Community-based Seed Producers. Thirty participants from research, extension, community groups and NGOs attended this course held in Rampur, April 4-6.

- Computer use for data analysis. Held in the CIMMYT-Kathmandu office, this course was structured to allow for one-on-one training, with each participant having access to a computer. Participants used their own field data as part of the training. Nine research officers from Lumle (2), Kabre (2), Pakhribas (2) and Rampur (3) participated in this training, which was held during the first two weeks of November.

Two scientists attended the 6-month crop management research training course in Njoro, Kenya. The Coordinator of the NMRP, Krishna Adhikari, attended the one-month, advanced breeding course in CIMMYT-Mexico in August. Mr. D. B. Gurung, Station Chief at Dailekh, attended a training course on participatory rural appraisal techniques in November in the Philippines. His participation was partially funded by CIMMYT's Upland Project (IFAD funding).

Challenges and Risks. The Maoist insurgency has intensified in several areas of Nepal. Nevertheless, project activities are continuing at all key stations and associated outreach sites. CIMMYT staff did not visit Dailekh ARS during the year as a result of security concerns. A shortage of staff, particularly in Dailekh and Kabre, constrained the project during the first half of the year.

Conclusion

The first two years of the HMRP have been devoted largely to identifying priorities, developing research strategies, and building research capacity within NARC. Priorities were established through a systematic process of meeting with farmers, reviewing geo-referenced data provided by the Nepal Country Almanac, and seeking advice from experienced researchers. As a result, a number of research topics that were not initially targeted by the project have now beem identified as priorities. The project has been able to draw on expertise from CIMMYT's global program, a soil scientist from Africa, an entomologist from Mexico, and breeders from Thailand and Zimbabwe to help establish an effective research strategy.

During this period the HMRP brought to Nepal and tested the most advanced genetic material from CIMMYT's global breeding programs. Several new varieties superior to those currently recommended were identified. Furthermore, the national maize program now knows where to obtain adapted materialsand NARC-CIMMYT collaborative varietal development programs have been established. Materials from CIMMYT-Zimbabwe are doing exceptionally well in the mid-hills of Nepal, and more focused testing of materials from Zimbabwe will allow for more efficient exploitation of CIMMYT's genetic resources in the future.

Lack of seed production seriously constrains the movement of new varieties within Nepal. The project has been successful in promoting community based seed production. Although a modest amount of seed is being produced, the methodology for teaching farmers how to produce seed within a community is now in place and well tested. This will increase the likelihood of new varieties moving beyond the research station and into the farmers' fields. The project has been able toestablish a sound foundation upon which to build insubsequent years.

Quality Protein Maize: Improved Nutrition and Livelihoods for the Poor

*Hugo Córdova**

Introduction

Maize is a major food for millions of the poor in Africa and Latin America. During the last few decades, CIMMYT scientists have developed and improved a quality protein maize (QPM) that looks and tastes like normal maize, yields as much or more, and shows equal or superior disease and pest resistance. But QPM contains nearly twice the lysine and tryptophan—amino acids essential for protein synthesis in humans and monogastric animals—plus agenerally mor e balanced amino acid content that greatly enhances its nutritive value. Research suggests QPM can help reduce protein deficiencies, particularly in young children, in settings where maize dominates diets. In Colombia, Guatemala, and Peru, malnourished children have been restored to health on controlled diets using quality protein maize. In addition, repeated studies in several countries have shown that pigs or poultry raised on QPM-based feeds gain weight faster and produce more than animals raised on normal maize-based feeds.

Since 1997, the Nippon Foundation has helped CIMMYT bring QPM within reach of millions of maize farmers and consumers in developing countries (Table 1). Through the Nippon-funded project "The Improvement and Promotion of Quality Protein Maizein Selected Developing Countries," CIMMYT and its partners have:

- Developed stable, high-yielding, disease-resistant QPM hybrids and synthetic varieties for diverse production settings.
- Tested QPM extensively on-farm and in demonstration trials.
- Promoted QPM in countries where maize is a staple and where the probability of adoption and impacts is high.
- Enhanced QPM seed production and distribution.
- Provided training on QPM research and dissemination.
- Conducted trials on the use of QPM in animal feed.

Table 2 provides a detailed accounting of activities and achievements during 1997-2000. The following is a summary of the chief aspects, as well as an examination of the lessons learned and an outline of future directions.

Progress and Products

Yield. Superior QPM hybrids and varieties identified through multi-location testing have been evaluated in more than 40 nations. In results, QPM hybrids often had a yield advantage of 1.0 t/ha or more over the best normal hybrid checks (Fig. 1), and yields of open pollinated varieties (OPVs) of QPM have equaled or exceeded those of normal maize. CIMMYT researchers have formed thousands of improved experimental QPM varieties for future testing and use. The groundwork has been laid for using DNA markers to help transfer quality protein genes to elite cultivars of normal maize. New QPM synthetics[9] feature special characteristics such as low and uniform ear

* CIMMYT maize breeder.

[9] "Synthetics" are open-pollinated varieties (OPVs) formed by inter-crossing 8 to 10 inbred lines known to combine very well (i.e., their progeny are outstanding) among themselves. Synthetics offer yields superior to those of normal OPVs but, as with all OPVs, seed from the previous harvest can be sown the following season without losing yield or desirable qualities. This is an advantage for poor farmers, who cannot afford to buy new seed year after year (a requirement in the case of hybrids, for example).

placement, resistance to ear rot and root lodging, and (most notably) levels of tryptophan (0.11% of the whole grain), lysine (0.475 % of the whole grain), and protein (11.0% of the whole grain) far beyond those contained in normal maize (0.05, 0.225, and 8.5%). These features make the QPM synthetics particularly attractive to farmers.

Converting Normal Elite Lines to QPM. Ten normal elite lines—parents of high-yielding tropical, subtropical, and highland hybrids of normal endosperm—were converted or are in the final stepsof conversion to QPM. This means that QPM hybrids with high yield potential will be available for a range of environments. The news is especially significant for the highlands, an ecology for which no QPM varieties are currently available.

Dissemination. Research and certification agencies of 19 countries have released dozens of QPM hybrids and varieties for use by farmers since 1998 (Table 2). Releases have been promoted through ceremonies and field days involving farmers, researchers, VIPs, and the media. In 1998 six hundred tons of parental seed for QPM hybrids was produced in Mexico alone, and seed production methods have been greatly refined.

Table 1. QPM varieties released since 1996.

Name	Type	Pedigree	Country
HQ INTA- 993	Hybrid	(CML144 x CML159) CML176	Nicaragua
NB- Nutrinta	Open pollinated	Poza Rica 8763	Nicaragua
HB- PROTICTA	Hybrid	(CML144 x CML159) CML176	Guatemala
HQ- 61	Hybrid	(CML144 x CML159) CML176	El Salvador
HQ- 31	Hybrid	(CML144 x CML159) CML176	Honduras
Zhongdan 9409	Hybrid	Pool 33 x Temp QPM	China
Zhongdan 3850	Hybrid		China
QUIAN2609	Hybrid	Tai 19/ 02 x CML171	China
Shaktiman-1	Hybrid	(CML142 x CML150) CML176	India
Shaktiman-2	Hybrid	CML176 x CML186	India
ICA	Hybrid	(CML144 x CML159) CML176	Colombia
Susuma*	Open pollinated	Across 8363SR	Mozambique
Obatampa*	Open pollinated	Across 8363SR	Mali
Nalongo* ?	Open pollinated	Across 8663SR	Uganda
Obatampa*	Open pollinated	Across 8363SR	Benin
BR- 473	Open pollinated		Brazil
BR- 451	Open pollinated		Brazil
Assum Preto	Open pollinated		Brazil
Obatampa*	Open pollinated	Across 8363SR	Burkina Faso
Obatampa*	Open pollinated	Across 8363SR	Guinea
QS- 7705	Hybrid		South Africa
GH- 132- 28*	Hybrid	P62, P63	Ghana
BHQP-542	Hybrid	(CML144 x CML159) CML176	Etiopia
INIA	Hybrid	CML161 x CML165	Peru
FONAIAP	Hybrid	(CML144 x CML159) CML176	Venezuela
HQ- 2000	Hybrid	CML161 x CML165	Vietnam
In Mexico, 21 hybrids and 5 open pollinated varieties including…			
H- 44IC	Hybrid	CML186 x CML142	Mexico
H- 367C	Hybrid	CML142 x CML150	Mexico
H- 553C	Hybrid	(CML142 x CML150) CML176	Mexico
H- 519C	Hybrid	(CML144 x CML159) CML176	Mexico
H- 368C	Hybrid	CML186 x CML149	Mexico
H- 469C	Hybrid	CML176 x CML186	Mexico
VS- 537 C	Open pollinated	POZA RICA 8763	Mexico
VS- 538 C	Open pollinated	ACROSS 8762	Mexico

* Sasakawa- Global 2000, a non-governmental organization dedicated to ending malnutrition and poverty in Africa and a leading promoter of QPM in the region, cooperated with national programs and CIMMYT for the release of these varieties.

CIMMYT's international maize testing unit has responded to hundreds of requests for QPM seed from more than 30 countries, as well as annually shipping nearly 400 trials involving more than 800 hybrids and varieties to sites throughout the developing world. Extensive on-farm testing of QPM crosses took place in Africa in 2000: more than 200 trials were conducted in 11 nations (Angola, Congo, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mozambique, Tanzania, Uganda, and Zambia). In Guizhou Province, one of the poorest regions of China, a government program provided farmers credit to buy pigs and raise them on QPM. Earnings have allowed inhabitants to build houses and undertake community development activities, in addition to achieving household food security. Additional QPM releases are expected in Colombia, Honduras, India, Peru, Vietnam, Venezuela, Ethiopia, Kenya, Uganda and Malawi in 2001-2002.

Protein Quality. Lab equipment for enzyme linked, immunosorbent assay analysis (ELISA; a rapid way to test for protein quality) was purchased for China, India, and Zimbabwe, and scientists were trained in its use. Innearly all trials, QPM hybrids had 70 to 100% more lysine and tryptophan than their normal maize competitors. Some new hybrids contain as much 12.5% protein—3.5% more than their normal maize counterparts. Because QPM is a recessive trait, normal, non-QPM is dominant. This means that, if QPM is fertilized by pollen from normal maize, the enhanced protein quality will be lost. However, several years of field tests have shown that pollen contamination of QPM varieties from normal maize fields is somewhat less than originally feared. Typically, protein quality in the grain of even the outermost rows will be reduced on the order of only 10% in a QPM field surrounded by normal maize. Further inside the QPM plot, little or no protein quality is lost. This of course can vary significantly, according to wind speed and direction, and careful monitoring of protein quality is required in seed production and maintenance, to keep high standards of protein quality. When choosing seed for future sowings, farmers should always select from plants near the center of theplot.

The World Food Prize, QPM History, and Partners

Maize breeder Surinder K. Vasal and cereal chemist Evangelina Villegas shared the 2000 World Food Prize for their efforts at CIMMYT over the 1970-80s to develop QPM. The Prize is awarded annually to individuals who have advanced human development by improving the quality, quantity, or availability of food in the world. Vasal capitalized on traditional breeding techniques to incorporate a series of special genes that countered the unwanted side-effects of *opaque-2,* a gene for protein quality discovered in maize in 1963. To ensure that the value-added protein trait was retained during crossing and selection, Villegas and her lab group painstakingly measured amino acid content in the protein of some 20,000 maize grain samples each year. By the mid-1980s, the team had developed QPM—a product much like normal maize, but with nearly double the lysine and tryptophan.

During the 1980s and early 1990s, other CIMMYT breeders—notably Magni Bjarnason and Kevin Pixley—developed high yielding QPM varieties for several developing country production niches. Sasakawa Global 2000, an international organization that works to spread improved farm technology in Africa, successfully promoted QPM in Ghana and several other African nations. Brian Larkins of the University of Arizona, USA, has provided valuable assistance in ELISA analysis. Norman E. Borlaug, Nobel Peace laureate and president of the Sasakawa Africa Association, has strongly endorsed QPM research and use. CIMMYT breeder Hugo Córdova and colleagues have spearheaded international QPM development, testing, and dissemination efforts under the Nippon-funded project.

Partners in this work have included the national maize research systems in Bolivia, Brazil, Central America, China, Colombia, Ethiopia, Ghana, India, Kenya, Malawi, Mozambique, Peru, Tanzania, Thailand, Uganda, Venezuela, Vietnam, and Zimbabwe; Sasakawa-Global 2000 (SG2000), the Sasakawa Africa Association (SAA), World Vision International (WVI), the Fundación Patiño, Maseca, Demasa, Milpareal, Texas A&M University, and other major non-government organizations.

Future Directions

We will continue emphasizing the development and testing of new hybrids and synthetics resistant to diverse biotic and abiotic stresses, as well as exploring new schemes to shorten the time of conversion of normal elite lines to QPM.

The CIMMYT Maize Program also participates in two major projects[10] to develop, test, and promote stress tolerant maize for farmers in sub-Saharan Africa. Both are incorporating the quality protein trait into the experimental varieties they develop and adapting elite QPM for use by farmers in the region.

Finally, from their work on QPM, CIMMYT researchers have learned the following valuable lessons:

Seed Production. Seed production for QPM hybrids and varieties should follow the normal and stringent quality control measures observed to produce high quality seed of normal maize. In addition, the protein quality of QPM should be assayed carefully at least once a year, using techniques such as ELISA and tryptophan analysis, during all stages of seed production. It is especially important to monitor protein quality when producing breeders' and basic seed, to avoid losses of lysine and tryptophan in subsequent steps (seed increases, commercial seed production, farmers' commercial grain).

Promotion. New tropical and subtropical QPM hybrids and varieties compete well in quality and yield potential with normal seed industry offerings for those ecologies. Nonetheless, active promotion using varied approaches—on-farm trials, verification trials, demonstration trials—is required to familiarize farmers with the best performing and adapted hybrid or variety for a given production setting. A minimum of two years of on-farm testing and verification are needed. Hybrids can be released in the third year before planting season starts and demonstration plots are planted. Varieties should never be released without testing, and this must be done in their area of adaptation (for example, subtropical varieties should not be testing in a tropical region). Great care must be taken with seed quality: forexample, germination should be checked before planting trials.

Seed production should be associated with the promotion of hybrids from the outset. Commercial seed producers should be involved in the transfer of QPM technology, to ensure successful promotion, as has been the case in El Salvador and China. The potential interest in QPM of a range of other commercial organizations has been used to enlist their participation in promoting this specialty maize. These include farmer associations (such as Agroportuguesa in Venezuela), swine growers (Mexico), the milling industry (El Salvador, Guatemala, Honduras), and the poultry industry (Colombia).

[10] See "Stress-tolerant Maize for Farmers in Sub-Saharan Africa," p.1.

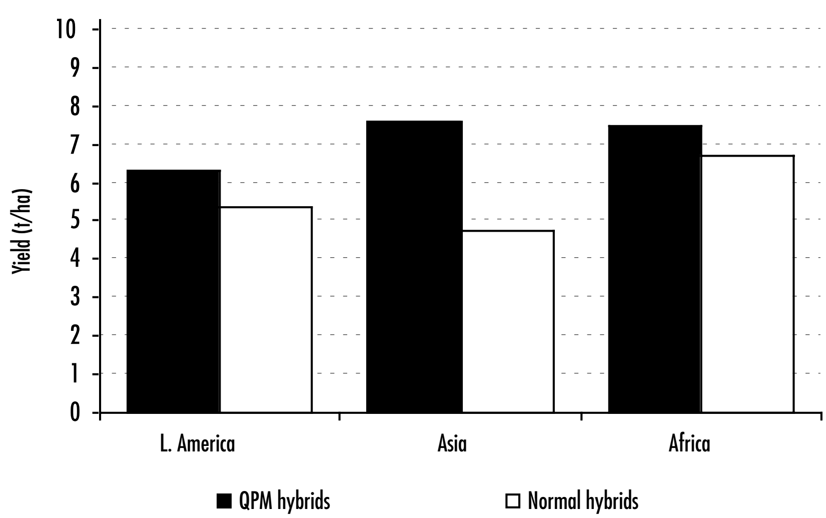


Figure 1. Yield of QPM and normal maize hybrids in tests at 33 locations in Africa, Asia, and Latin America, 2000.

Table 1. Activities and achievements in QPM research, testing, and promotion, 1997-2000.

	1997	1998	1999	2000
Dissemination	Brazil releases one yellow grain QPM hybrid and Ghana two white grain QPM hybrids.	Releases in Benin, Burkina Faso, and Guinea by Sasakawa-Global 2000 and in Brazil.	National programs release 12 QPM hybrids and 4 open pollinated varieties in Mexico; 1 hybrid each in China, El Salvador, Guatemala, and Peru. * CIMMYT ships seed to 29 countries in response to more than 180 requests.	National programs release a hybrid in Guatemala and OPVs in Mozambique and Uganda. * Produce basic seed of QPM for demonstrations in China, Ethiopia, Ghana, India, Nicaragua, Peru, Vietnam, and Zimbabwe.
Testing	Brazil, Ethiopia, Guatemala, India, Mexico, Mozambique, Ghana, South Africa, and Thailand * Tropical and subtropical QPM hybrids in Mexico, India, Zimbabwe, South Africa, and Mozambique significantly out-yield commercial hybrids.	Well underway in Brazil, Colombia, El Salvador, Ethiopia, Ghana, Guatemala, India, Mexico, Mozambique, South Africa, Thailand, and Zimbabwe. Begun in Bolivia, Honduras, Malawi, Mali, Nicaragua, Peru, the Philippines, and Uganda. * Tropical and subtropical QPM hybrids again yield much more than commercial checks and possess superior protein quality.	Superior hybrids and open-pollinated varieties of quality protein maize (QPM) evaluated in more than 30 nations often had a yield advantage of one ton or more per hectare over the best normal maize hybrids. * QPM hybrids have 70 to 100% more of the essential amino acids—lysine and tryptophan—than their normal maize competitors.	More than 200 trials conducted in Angola, Congo, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mozambique, Rwanda, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe. Yield and disease resistance *at least* comparable to the best African materials. * Field test results show that pollen contamination of QPM varieties from normal maize is far less than originally feared. * Lab tests show some new QPM hybrids contain as much 13.5% protein—at least 30% more than normal maize.
Promotion		Two field days in Mexico attended by hundreds (farmers, agriculture secretaries, researchers and directors, agricultural industrialists, among others) result in Mexican plans to launch a major QPM production and promotion program in early 1999.	Gala ceremonies and field days in Mexico, El Salvador, and China; nearly 2,000 farmers, as well as researchers and VIPs (including CIMMYT DG and Nippon representatives) participate. * The CIMMYT Annual Report features a major story on QPM.	The award of the World Food Prize to the scientists who developed QPM at CIMMYT during 1970-85 focuses global attention on QPM.
Germplasm development, formation, and seed production	Increase seed of best 1991 QPM lines for evaluation by national programs. * Improve resistance of QPM lines to crop diseases. * Field-test 600 inbred lines and develop hybrids. * Form 1,000 new inbred lines.	Produce more seed of the best tropical and subtropical hybrids and varieties for extensive evaluation at more than 100 locations in 10 priority countries during 1999. * Produce seed of one SC hybrid 9009 in China.	Form more than 1,500 new, experimental QPM hybrids. * Increase seed of 20 key synthetics and of 28 inbred parents. * Produce 17.5 tons of parental seed of the new QPM hybrid, Zhongdan 9409, in China; distribute 67 tons of hybrid seed in Guizhou Province. * CIMMYT delivers 2.5 tons of hybrid progenitors and single-cross hybrid seed to Mexican agencies, which produce 500 tons of registered seed of hybrids and va rieties.	New tropical QPM synthetics offer yields superior to those of normal varieties but allow seed to be saved and sown the following season — an advantage for poor farmers who cannot afford to buy hybrid seed. * CIMMYT develops QPM versions of its most important tropical and subtropical inbred lines and is doing the same for highland lines.
Laboratory methodologies	Identify molecular markers for protein quality and kernel hardness genes.	Continue to identify molecular markers for the genes associated with protein quality and kernel hardness. * Begin backcrosses to transfer QPM genes into outstanding conventional inbred lines.	Purchase lab equipment for enzyme linked, immunosorbent assay analysis (ELISA; a rapid way to test for protein quality and a crucial component of QPM breeding) for India and China, train scientists in its use.	Backcrossing assisted by molecular markers to convert normal, tropical white inbred lines (CML 264 and CML 273), to QPM.
Training	Two visiting scientists—one from Mexico and one from Ghana—work on QPM at CIMMYT.	Three visiting scientists — one each from Mexico, Ghana, and Ethiopia — participate for several months in QPM research at CIMMYT.	Hold training course on seed production in Zimbabwe for researchers from sub-Saharan Africa and Brazil. * The Project helps support QPM research of a visiting scientist from Ethiopia.	Training events on various aspects of QPM research were conducted by CIMMYT staff in Africa, Asia, Latin America and at CIMMYT headquarters.

Storage Pest Resistance In Maize

David J. Bergvinson[*]

Maize is a major food crop in Africa and the Americas as well as a feed crop for these regions and Asia. Genetic gains in yield have been achieved but these gains are not always realized at the farm level due to the challenging environments maize faces. One important factor that reduces yield and yield stability is the pressure placed on the crop by insect feeding throughout the cropping cycle (Fig. 1). During the vegetative and grain filling stages, insects such as stem borers and armyworm cause on-farm losses in the range of 5 to 30%. Additional losses are caused by several different post harvest pests, with some areas such as the lowland tropics of Mexico suffering 100 percent kernel damage and 30% weight loss during 6 months of storage. This report describes CIMMYT's work to develop insect resistant maize and related technologies, and ends by focusing on significant recent advances in research on resistance to insect pests of stored grain.

An Overview of Entomology Research

The Maize Program is well equipped for research on resistance to insect pests. In addition to its extensive collections of tropical maize seed, representing a considerable portion of maize genetic diversity, the Program also has the required infrastructure and technical expertise to screen germplasm for resistance. Even so, developing insect resistant maize is a difficult task: resistance is a polygenic trait (seven important QTLs have been identified) and proper screening requires that healthy insects for infestation become available at the crop development stages when experimental plants are most susceptible.

The Program is currently using two strategies to increase the level of insect resistance: 1) eliminate the most susceptible germplasm from our main breeding populations, and 2) develop source germplasm with

* Entomologist, Maize Program.

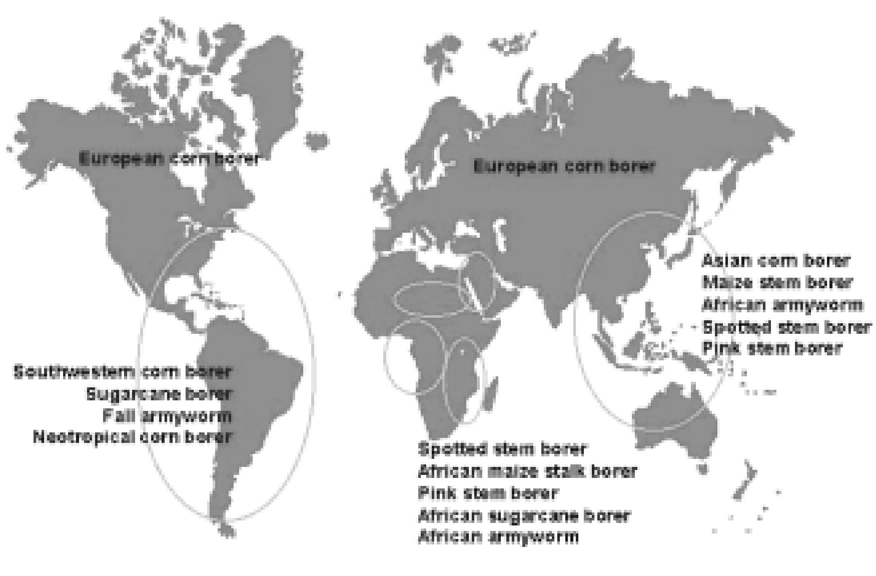


Figure 1. Distribution of important insect pests of tropical maize in the field.

elevated levels of resistance for incorporation into CIMMYT's elite lines and populations (Fig. 2). Thus, our main breeding populations have become more tolerant to insect pests and our source populations have improved in their agronomic performance. Since CIMMYT has only one insect rearing facility for borers and armyworm, the entomology unit also screens lines developed by our regional programs. During evaluation, elite lines developed at outreach offices are crossed to insect resistant lines for selection under insect pressure as well as adaptation to regional stresses (i.e. local diseases, drought). This process of "shuttle breeding" is an effective means of developing insect resistant germplasm that is adapted to the target environment.

There have been good gains in developing insect resistant maize populations, with CIMMYT germplasm serving as a source material for not only tropical maize but also temperate maize (Fig. 3). The entomology unit uses a breeding process called S_3 intra-population improvement to concentrate the resistance alleles into maize lines. Lines thus produced are transferred to breeders in Mexico and regional offices for incorporation into breeding populations.

The resistance mechanism has been well characterized through research by CIMMYT's entomology unit and through molecular mapping in collaboration with the CIMMYT Applied Biotechnology Center. The two major components involve reduced leaf nitrogen content (below 2.3% N) and increased epidermal cell wall toughness of the leaves. The first mechanism is not practical, because reducing N content in plant tissue also reduces yields. However, leaf toughness does not pose a risk to yield, as it involves a thicker epidermal cell wall (Table 1) and higher levels of phenolic dimers localized in the cell wall. We have utilized this information to identify breeding populations that have the best chance of producing insect resistant germplasm that yields well. This technology is now being used in Kenya to assist in the selection of lines to be considered in the Insect Resistant Maize for Africa (IRMA) project. The criterion is that they combine both conventional insect resistance with transgenic (Bt) resistance to deliver a durable and effective level of stem borer resistance for Kenyan farmers.

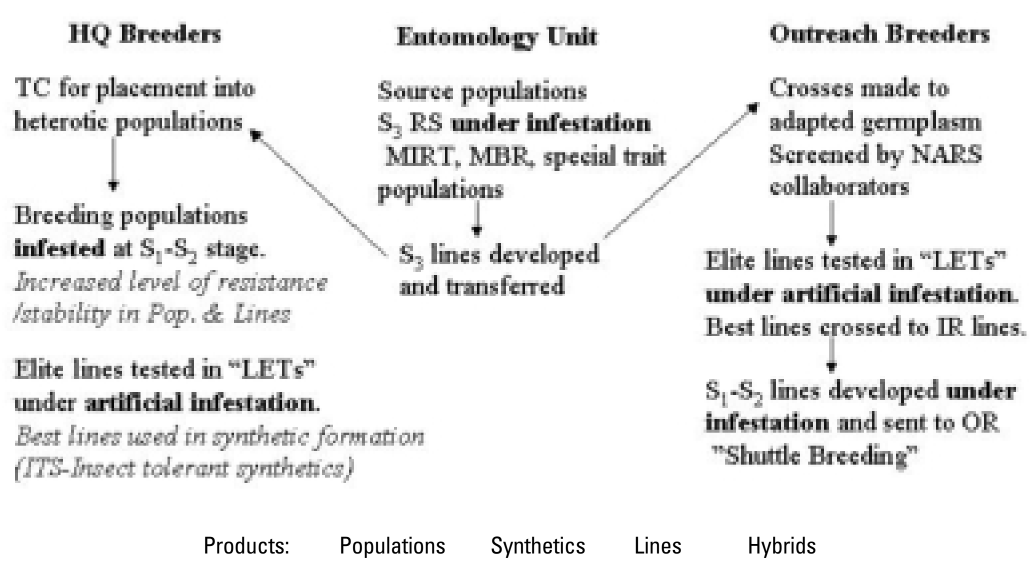


Figure 2. The CIMMYT Maize Program's approach for developing insect resistant germplasm (LET = line evaluation trial).

In developing countries the maize crop normally faces many stresses simultaneously. For this reason, research was initiated to look at the interactions between drought and the effects of infertile (low nitrogen) soils and yield reductions associated with insect pests. Our original work focused on superior performance (i.e., reduced insect attack and percent yield losses) under zero nitrogen (i.e., where no fertilizer was applied). We have since worked with the timing of optimal nitrogen rates to identify the optimal timing of nitrogen application to reduce insect establishment and increase yield. Delaying nitrogen applications to two weeks before flowering reduced insect attack and increased yield but also increases the incidence of ear rots. For regions where insect damage is severe and nitrogen limiting, delayed applications may be considered. Another important interaction identified is the synergism between drought and stem borer damage in reducing yield (Fig. 3). From this work, it is evident that drought tolerance and stem borer resistance are an important combination for African germplasm, especially in regions were insect pressure is consistent. We are recycling the best drought tolerantlines fr om CIMMYT's Zimbabwe program with insect resistant lines form Mexico to address thisneed.

Regarding quality protein maize (QPM), one limitation to adoption has been its susceptibility to biotic stresses, the most notable being weevils during storage. Testing of experimental QPM varieties for weevil resistance has been initiated to identify varieties with good levels of resistance (see more below). There are QPM varieties that show good better weevil resistance than conventional hybrids. Testing for weevil resistance will be an important component in QPM characterization (Fig4).

The Entomology Unit is also involved in testing and developing transgenic maize containing the *Bacillus thuringiensis* (Bt) gene. This involves the testing of putative transformed events, looking at the rate of insects developing resistance, designing insect resistance management strategies for developing countries, and estimating impacts on non-target organisms. This work links with that of the IRMA project, which focuses on developing insect resistance maize for Kenya by using both conventional and transgenic sources of insect resistance. In Kenya, farmers report losing 15% of their maize harvest to stem borers, equivalent to 400,000 t of maize each year valued at US$ 90 million. Farmers in some areas have reported losses as high as 45%. By bringing conventional resistance together with Bt resistance, we can offer maize with efficient and durable resistance for tropical ecologies where insect associated losses are most severe.

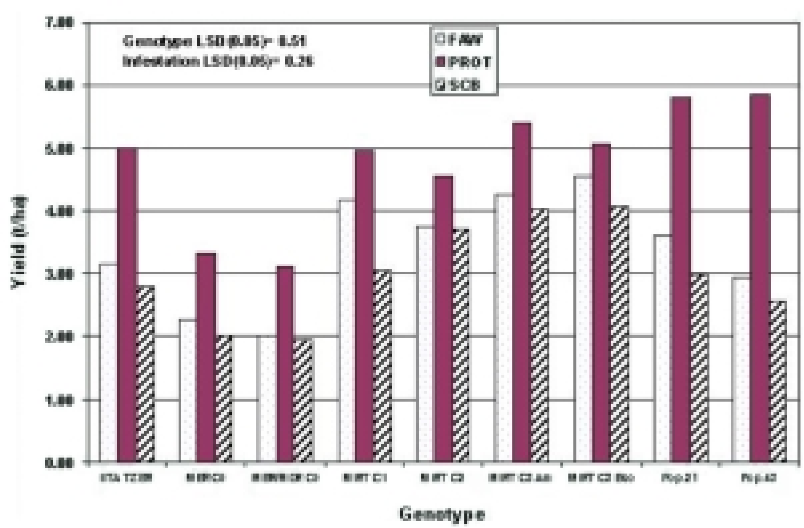


Figure 3. Gains in yield potential under artificial insect infestation in the Multiple Insect Resistant Tropical, or MIRT, population over cycles of selection.

Research on Storage Pest Resistance

Although many modern maize varieties and hybrids possess improved agronomic performance and tolerance to abiotic and biotic stresses, traits that contribute to improved grain storage have been largely ignored. This characteristic is particularly important in developing countries, where grain is often for domestic use and stored under adverse conditions. Insect pests that attack stored grain tend tohave rapid rates of r eproduction and both consumegrain and contaminate it with insect parts and excrement. For maize, these losses usually amount to 5-15% in developing countries, with on-farm surveys in Mexico generating a mean of 30% kernel damage largely by the maize weevil (*Sitophilus zeamais*) and the larger grain borer (*Prostephanus truncatus*) (Tigar et al. 1994).

Researchers have known for more than two decades that genetic variation for resistance to storage pests exists in maize. Widstrom et al. (1975) investigated the inheritance of resistance to maize weevil with 80 maize inbred lines in a no-choice study. Maternal dominance effects were found important but not cytoplasmic effects. Using a 10–line diallel, Tipping et al. (1989) found that, under no-choice conditions, general combining ability was more important than specific combining ability. Additional studies that have used germplasm with more diversity have also confirmed the heritability of weevil resistance but the relatively low, broad-based inheritance observed for this trait would imply slow progress in moving the trait into elite germplasm (Li et al. 1998; Derera et al. 2001a,b). The challenge now is to utilize this variation in modern breeding programs focused on tropical maize normally stored under adverse conditions.

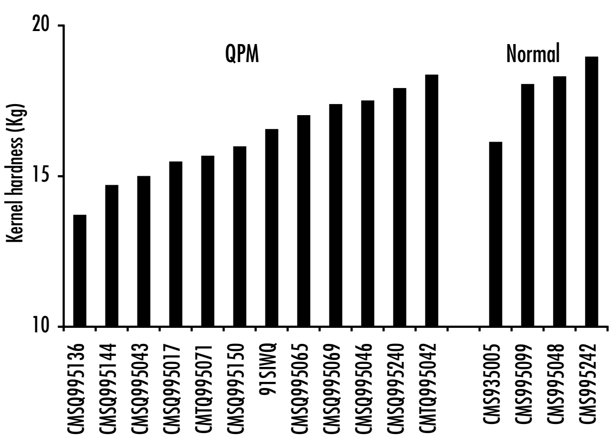


Figure 4. Characterization of quality protein maize (QPM) for kernel hardness as a means of identifying varieties prone to attack by post harvest pests.

Early research to elucidate the mechanism of resistance has found through fluorescence microscopy (Serratos et al. 1987) that the pericarp of resistant maize genotypes was highly fluorescent. This was attributed to high concentrations of hydroxycinnamic acids (simple phenolics) located within the pericarp. These phenolics are bound to the arabinoxylans within the cell wall. Subsequent research using 15 CIMMYT pools and populations correlated maize weevil resistance (number of eggs laid, number of progeny, Dobie Index, grain consumption) with E-ferulic acid, protein content, and kernel hardness (Classen et al. 1990). Screening of Mexican landraces allowed the identification of resistance sources, with the ancient indigenous races, such as Sinaloa 35 and Yucatan-7, being among the best (Arnason et al. 1994).

An understanding of the inheritance of biochemical / biophysical factors has been achieved by generations mean analysis (Serratos et al. 1997). This study estimated genetic variation using linear models that related biochemical and biophysical factors to susceptibility indices of selected genotypes. Dominance of endosperm-pericarp for phenolics in the grain and dominance of the pericarp for phenolics, maximum kernel force of compression and index of susceptibility were highly significant, indicating that phenolics do have a role in weevil resistance expressed in the pericarp.

Our research is now focused on furthering our understanding of the limitations of these biochemical resistance factors in maize, constructing molecular maps to identify quantitative trait loci, and large-scale screening of CIMMYT germplasm (maize and wheat) to identify new elite sources of resistance and eliminate germplasm that is extremely susceptible prior to line release. These activities will be discussed below.

Biochemical basis of kernel resistance to post harvest pests. Given the demonstrated importance of kernel compression (Serratos et al. 1993), the entomology unit was interested in developing a rapid surrogate method to screen maize kernels for this trait. Using a Tricor Systems Inc. Model 921A Force-Displacement meter, a methodology was developed to measure the peak kernel force. The meter was fitted with a 22Kg load cell and a 0.8mm dia. probe with a rounded tip. Grain was equilibrated at 75% relative humidity and 27°C for 2 weeks prior to measuring. Under these conditions germplasm could be screened with good separation occurring between maize genotypes, as evidenced by the screening of QPM, which has the opaque-2 mutant that delivers higher levels of tryptophan and lysine but results in a soft endosperm and susceptibility to weevils (Fig. 4).

Using this technique, QPM varieties can now be screened for hard endosperm, with segregating populations being improved for kernel hardness. This is possible because the same kernels that areused for evaluation can be regenerated to accelerate breeding progress in endosperm modification. The germination rate after kernel measurement is ca. 85-90% when kernels are incubated at 30°C and 100%RH for 3 days prior totransplanting.

Given the importance of kernel hardness and theability to measur e this trait rapidly in the lab, our group conducted a study to quantify the relationship between grain moisture content (GMC), kernel hardness, and resistance to *S. zeamais* and *P. truncatus*. Figure 5 shows the relationship we observed using environmental growth chambers set at different levels of relative humidity (40, 60, 80 and 100%) and 27°C. At a GMC below 12%, the resistant genotype (Population 84) derived from Caribbean and Cuban bank accessions provided effective control for both insect species. However, once the GMC reached 16% the resistant and susceptible (CML244xCML349) entries showed similar damage levels. Kernel hardness also dropped with increasing GMC, indicating the limitation of this resistance mechanism.

These results highlight the importance of grain conditioning prior to storage. CIMMYT is working to develop low cost grain drying systems as part of an integrated post harvest management strategy for resource poor farmers.

The relationship between kernel hardness and biochemical factors is now being refined, with the advent of more sophisticated HPLC techniques for quantifying phenolics. One group of phenolic

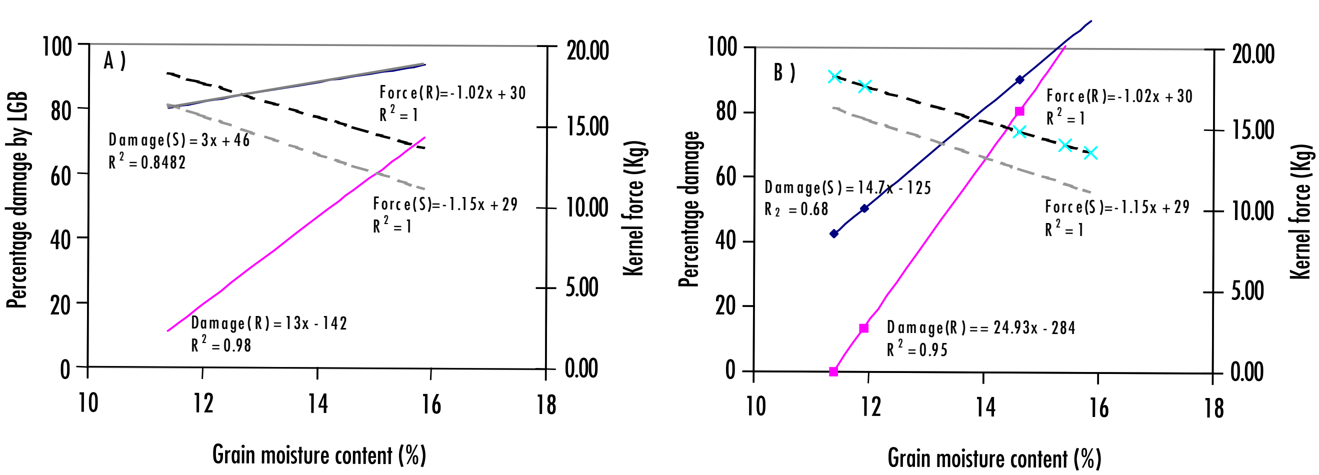
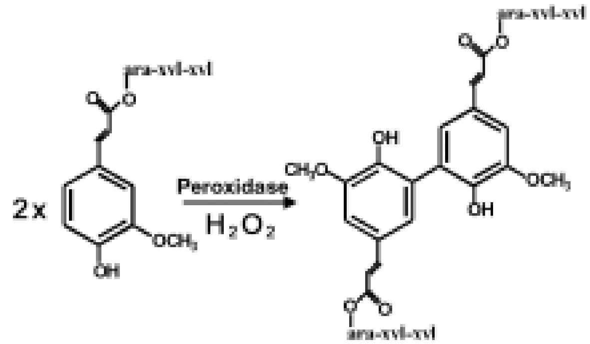


Figure 5. Relationship between insect resistance [solid lines] and kernel force (Kg/mm2) [dashed lines] using a resistant (Population 84) [black lines] and susceptible (CML244xCML349) [grey line] genotypes of maize. Graph A) *Prostephanus truncatus* and B) *Sitophilus zeamais.*

compounds that have received considerable attention in the past decade are the phenolic dimmers which cross-link hemicelulose within the cell wall. Difeluric acid is one such dimmer and is under enzymatic control (Fig. 6).

Given the genetic and biochemical compositions of the different kernel tissues (endosperm, germ, pericarp), our group has used tissue-enriched fractions generated from a peril mill to conduct biochemical research. The reason for this is the dilution associated with the endosperm that constitutes 70% of the sample compared to around 5-8% for the pericarp. Using this technique, phytochemical analysis as described in Arnason et al. (1994) was used to correlate the different putative resistance factors with kernel resistance against *S. zeamais* for each tissue type (endosperm, germ, pericarp). The study consisted of 7 genotypes representing a wide range in resistance (Table 1).



Ferulic acid   Dehydrodiferulic acid

Figure 6. Peroxidase-mediated formation of diferulic acid formed in the cytosol and used as a cross-linking agent in cell wall formation.

Table 1. Correlation of weevil resistance and putative resistance factors using enriched-tissue fractions from seven maize genotypes.

Tissue†	Damage by *S. zeamais*	Kernel hardness	Nitrogen	Fiber	Sugars	Total DFA
Embryo						
Kernel hardness	-0.71					
Nitrogen	-0.61	0.23				
Fiber	0.11	-0.57	0.28			
Sugars	0.42	-0.61	0.22	0.88*		
Total DFA	0.45	-0.92*	0.00	0.82	0.75	
Ferulic acid	0.52	-0.83	0.28	0.68	0.81	0.84
Endosperm						
Kernel hardness	-0.97**					
Nitrogen	-0.70	0.63				
Fiber	0.53	-0.56	0.15			
Sugars	0.39	-0.29	0.12	0.79		
Total DFA	0.40	-0.47	-0.72	-0.27	-0.48	
Ferulic acid	0.41	-0.40	-0.84*	-0.51	-0.51	0.86**
Quality Index	0.03	-0.09	0.28	0.69	0.55	-0.11
Pericarp						
Kernel hardness	-0.97**					
Nitrogen	0.89*	-0.95**				
Fiber	0.19	-0.20	0.00			
Sugars	0.86*	-0.92**	0.91**	0.05		
Total DFA	-0.91**	0.86*	-0.82*	-0.12	-0.63	
Ferulic acid	-0.80	0.71	-0.55	-0.51	-0.42	0.88*

† Correlations in bold have a P-value <0.07, * P<0.05, **P<0.01.

Thedifer ulic acids were most important for the pericarpexpr ession of resistance and included 5-5DFA, 8-O-4DFA, and 8-5DFA.

Molecular mapping of weevil resistance in tropical maize. Based on early studies of CIMMYT populations, two varieties were selected under weevil infestation for improved resistance. Nine mapping populations were created for both white and yellow tropical maize, with one F_2 population being selected based on the phenotypic range for kernel hardness and weevil resistance. This mapping population consisted of two lines derived from Population 28 (yellow tropical) to form an $F_{2:3}$ mapping population: 1) Muneng-8128 C0HC1-18-2-1-1 with moderate level of resistance and 2) line CML290, which was susceptible. The population consisted of 163 F_2 families that were selfed to generate F_3 lines that were subsequently bulk increased for phenotypic characterization. To generate the molecular map, 89 restriction fragment length polymorphisms (RFLPs) and 196 simple sequence repeats (SSRs) were used which showed clear polymorphism. Preliminary results from this mapping effort are shown in Table 2.

Conclusions

Maize germplasm with improved resistance against storage pests is clearly in high demand among small-scale farmers in tropical counties. CIMMYT has made progress in meeting this demand by identifying and developing source germplasm and new screening methods to advance germplasm improvement for resistance in maize to post harvest pests. With the development of source germplasm, biochemical studies characterized these sources of resistance and identified limitations in their use. Divergent selection studies are in progress to define the possible gains offered by conventional resistance to storage pests. Graduate students collaborating with CIMMYT have confirmed the importance of additive, non-additive, and maternal effects for weevil resistance. This has assisted in developing weevil tolerant hybrids, using the resistant line as the female parent in hybrid seed production. Lines have been identified that not only serve as a source for weevil resistance but also for resistance to grey leaf spot and maize streak virus, two diseases that limit maize productivity in sub-Saharan Africa, for use in recycling elite lines targeted for Africa. QPM varieties have also been screened to identify the most promising germplasm for weevil resistance.

Understanding the biochemical basis of insect resistance is important for both food safety and to determine the potential limitations of resistant sources. Good correlations between insect resistance and kernel hardness are also correlated with elevated levels of diphenolic acids located within the pericarp of the kernel. Kernel hardness as a resistance mechanism is limited by grain moisture content, with levels above 16% leading to susceptibility in resistant genotypes. This finding was important as it emphasized the importance of grain conditioning in delivering an integrated storage management package to resource poor farmers.

The development of a mapping population has enabled some putative QTLs to be identified, with a long-term goal of identifying robust QTLs for use in a marker assisted selection (MAS) program to rapidly incorporate weevil and larger grain borer resistance into elite lines targeted for tropical climates. The most efficient strategy for using MAS and conventional screening has yet to be defined, but clearly both methods are important in delivering elite germplasm which has a good level of resistance to post harvest pests.

Table 2. Quantitative trait loci for weevil resistance and putative resistance factors in a tropical yellow maize population (Population 28).

Chr.	Dist.	LR	Marker	Trait
1	42	12.07	bnlg1007	Kernel hardness
3	261	12.73	umc 63	Dobie Index
4	274	18.09/19.52	bnlg 1917	No.Weevils, Dobie Index
5	62	12.05	Phi113	Kernel Damage
5	70	12.39	phi113	Dobie Index
6	33/49	10.3/11.3	bnlg1538	Kernel Damage/Loss
7	180	12.71	umc149	Kernel hardness

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The CIMMYT Maize Program in 2000

*Shivaji Pandey**

There have been important changes in CIMMYT's Maize Program in recent years; they are briefly described here.

First, some general information about the extent of global maize production. Of the 100 million ha of maize planted in developing countries, about 42 million ha are planted in Asia, 30 million ha in Latin America, 26 million ha in Africa, and 2.5 million ha in West Asia / North Africa. In these regions, 50 million ha are in the lowland tropics, 18 million ha in the subtropics and tropical midaltitudes, 6 million ha in the tropical highlands, and 26 million ha in temperate ecologies. CIMMYT focuses mainly on non-temperate maize, as much of the technology for temperate maize is provided by the private sector.

In early 1998, we examined where we were, where we needed to go, what we needed to do, and with whom, to better serve the resource-poor maize farmers. One outcome of this exercise was the document, "CIMMYT's Maize Program: Strategic Directions, 1998 and Beyond." Basic principles described therein include the following:

- The Maize Program exists to work with partners to develop and distribute technologies appropriate for maize systems operated by resource poor farmers and to promote increased and sustainable maize production in developing countries, with the aim of meeting the growing demand for this cereal.
- Our priorities and niches should be determined by 1) those needs of our partners for which few or no suppliers exist and 2) what we can do more efficiently than our partners and provide to them at a lower cost or no cost at all.
- Our research, products, and services should improve food security, help alleviate poverty, and preserve natural resources in developing countries.

Here is what we had going for us:

- One of the largest functional maize gene banks, where we are preserving, regenerating, evaluating, and classifying more than 21,000 maize seed collections from different parts of the world, especially Latin America and the Caribbean.
- A large array of improved maize germplasm (gene pools, populations, OPVs, lines, and hybrids), suitable for developing countries.
- The largest public maize research and collaboration network through our international testing, training, and visiting scientist programs, involving the support and collaboration of nearly 4,000 national program scientists from 100 countries.
- We had highly experienced and dedicated maize scientists located strategically throughout the world.
- We had support from excellent scientists in CIMMYT's Economics Program, Natural Resources Group (NRG), and Applied Biotechnology Center (ABC), as well as highly qualified and motivated support and administrative staff.
- We had the facilities and equipment needed to develop appropriate technologies efficiently.
- We had the trust, confidence, respect, and support of partners, donors, leaders, and the CIMMYT Board of Trustees.

We were doing many things right and they needed to continue, but we also needed the following:

- A strengthened genetic resources and pre-breeding (development and improvement of gene pools, novel crosses between improved and exotic germplasm, among other things) unit, uniting the two activities.

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- A balanced germplasm development and enhancement program that provided partners with the means to meet farmers' needs—that is, high yielding, stress tolerant, agronomically desirable open pollinated varieties (OPVs) and hybrids—and that used an appropriate combination of modern and traditional technologies to do so.
- Greater balance and complementation between outreach and headquarters activities based on comparative advantage and allowing for the more efficient development and distribution of technologies and enhancing interactions with partners.
- A revived, aggressive, and pro-partner international testing unit and germplasm distribution system.
- Increased cooperation with the CIMMYT Economics Program, the NRG, and the ABC to enhance research efficiency, priority setting, and technology targeting and maximize spill-over benefits.
- Greater cooperation with partners, especially resource-endowed public partners, to increase the efficiency of germplasm and human resource development.

In less than three years after the above assessment, we are pleased to report gratifying progress on all counts. A few highlights:

Strengthened Genetic Resources and Pre-Breeding. There are few alternate suppliers of these two services, even though germplasm is the backbone of any breeding program. We asked the head of our gene bank to coordinate both activities and provided him with additional resources and personnel. Gene pools that were shelved have been brought back and new ones synthesized for major maize ecologies in developing countries. Twelve gene pools for the tropical lowlands and eight for the subtropics and midaltitudes are already available and are being improved using reciprocal recurrent selection. Ten gene pools for the highlands are being developed. Novel genotypes are being developed for breeders by crossing desirable bank accessions with elite CMLs, much like what is being done under the US Germplasm Enhancement of Maize Project (GEM) project. Some of these materials have been passed on to the breeders, and superior gene pool fractions will also begin to flow into breeding programs shortly.

Balance in Breeding. We agreed that temperate maize areas in developing countries were well served by our private and public partners and our strength was in germplasm for the lowland, highland, and midaltitude tropics. In addition, biotic and abiotic stresses, unfavorable policies, poverty, and others factors limit maize average yields in developing countries to only 2.9 t/ha (1.9 t/ha, if China, Brazil, and Argentina are excluded). Private organizations have historically focused less on research aimed directly at enhancing abiotic stress resistance, the public sector generally lacks the expertise or resources to do it, and non-government organizations are usually not research-oriented. Therefore, this must be one of the most important activities of our program. Today, stress and non-stress activities are integrated in our breeding research. Other changes include the following:

- Approximately 60% of the maize area in developing countries is planted to improved germplasm; 47% to hybrids and 13% to OPVs. Fifty-three percent of the farmers do not use hybrids, either because they cannot afford them or because suitable hybrids are not available. Poor and subsistence farmers in the marginal environments require stress tolerant, stable performing OPVs and hybrids and low-cost soil fertility management techniques. Commercial farmers in favored environments require profit-enhancing technologies based on high-yielding, stable performing, stress tolerant and input-responsive hybrids and accompanying agronomic practices. Reflecting these divergent needs, today the Program devotes about 55% of its efforts to hybrids and 45% OPVs.
- We agreed that some of our old germplasm, which no longer served the needs of our partners, needed to be shelved and new materials developed. We needed to switch to reciprocal recurrent selection based on heterotic populations to exploit heterosis. We have done both.
- We are now developing more uniform, productive, and stress tolerant synthetics, using inbred lines.

- For line development, we said we would use 60% pedigree breeding, 20% molecular-assisted line enrichment, and 20% selfing in improved populations and synthetics. We are almost there.
- We are doing more to develop and improve maize with enhanced levels of protein quality, zinc, and iron.
- We have developed and are following a new policy on the release of inbred lines. Among other things, it limits the number of lines released to only the best and most uniform, and stipulates that all lines must be made available with specific information on their adaptation and performance to facilitate their use by our partners.
- We wanted to address food vs. feed issues with maize. It is a very difficult task, and the Economics Program is leading a project for Asia that will shed light on the issue, which is more important in this region than in other parts of the world.

Division of Labor Between Outreach and Headquarters. We agreed that we must have strong programs at both the outreach and at headquarters. To avoid duplication of effort and ensure proper focus and coordination, we did the following:

- Because much of our impact to date comes from global public goods— germplasm, research methods, and information do not recognize political or geographic boundaries—our scientists at headquarters would continue to:
  1. Develop germplasm, research methods, and information that are global in scope; i.e., they are useful to our partners in Africa, Asia, and Latin America.
  2. Participate in and support research, training, and networking activities of outreach scientists.
- Outreach scientists would complement the headquarters efforts in technology development and training, especially in areas that cannot be handled in Mexico and where national programs require CIMMYT support. This slightly reduces research and increases development work (e.g., on-farm research, mother-baby trials, participatory research, seed production). Specifically, outreach scientists would:
  1. Adapt and fine-tune germplasm, information, and research methods developed at headquarters.
  2. Increase seed of superior germplasm from headquarters and outreach programs and provide them to our partners.
  3. Conduct strategic agronomic and systems research in collaboration with partners.
  4. Organize regional trials, using superior materials from headquarters, their own research programs, other outreach programs, and national programs.
  5. Ensure that our materials are evaluated under different regional conditions and the information is used in our selection to increase the usefulness of our products to our partners.
  6. Ensure that partners are aware of our products and services and evaluate and use them.
  7. Organize training courses on regionally important issues.
  8. Work directly with partners to identify superior technologies, produce and distribute seed, and promote relevant technologies.
  9. Foster collaboration among national programs in their region and facilitate the exchange of information, experiences, and technologies. Strengthen ties among public institutions, private enterprise, and non-governmental organizations involved in maize research and production to make technology development and adoption more efficient.

Outreach scientists spend now significantly more time on development work. They are participating in thousands of on-farm trials that address issues of soil fertility management, Striga control and Striga tolerance breeding, drought (especially in Africa), and soil acidity (especially in South America). We recently started a project in Kenya and Uganda to establish sustainable seed production systems for resource-poor farmers in areas where there are no alternate suppliers. The project involves all types of partners and is funded by the Rockefeller Foundation.

Revitalized and Pro-Partner International Testing. Wer ecognized that international testing provides us notonly with information to enhance the ef ficiency of our research program but also an excellent vehicle for showcasing and distributing our germplasm. As such, itis cr ucial to our success, so:

- We now ship more trials and germplasm than ever.
- All our trials are now centrally announced, so partners have access to all CIMMYT germplasm, regardless of whether it was developed at headquarters or in outreach.
- We include entries from other sites in trials originatingfr om a given site.
- We have put germplasm and trial announcements on-line.
- Time for returning results to partners has gone down from 21 to 3 days. And during 1998-2000 we cleared a backlog of six international testing reports (those for 1994-98, and a 1996 special report).
- We implemented a “key sites” approach for testing germplasm where the data will be used primarily for breeding. The objectives are to expose this germplasm to different types of environments, especially stresses, under which it will eventually be grown, and to use the information in selection. Most of these sites are our own outreach sites but occasionally they are operated by partners.
- Historical international testing data back to 1974 are now available on CD-ROM.
- All CIMMYT Maize Program scientists and many partnersar e using our Fieldbook program for trial design and pedigree and inventory management.

Collaboration with the Economics Program and the NRG and ABC. We continue to work with the NRG on natural resource issues. In addition, we and partners have found particular value in the NRG’s geographic information system (GIS) products, which help improve targeting and increase spillover benefits from our outputs and services. In the latter regard, we have worked recently with the NRG to refine maize mega-environment definitions,[11] and have contributed to development, promotion, and training activities for the *African Maize Atlas* and several *Country Almanacs*, including one on Nepal.

We have increased our collaboration with the Economics Program in impacts assessment and other areas. The study on Maize Program impacts in Latin America came out in 1999; those on Africa and Asia will be out this year. Another exciting area of collaboration is research priority setting. We are also working with CIMMYT economists on food vs. feed issues in Asia. Maize scientists interact with economists in regional programs on policy, adoption, and other issues. We are working with them on participatory breeding and farmer decision making , especially in Mexico and sub-Saharan Africa. Finally, the Economics Program completed a major study, with help from Maize Program staff, comparing the costs of DNA marker assisted selection and conventional breeding (Dreher, K., and M. Morris. 2000. A Close Look at Biotech Breeding Costs: The Details Make a Difference. Available at: www.cimmyt.org/whatiscimmyt/AR99_2000/future/a_close/a_close.htm.)

Collaboration with ABC staff in the use of molecular markers for QPM and breeding for resistance to maize streak virus is now routine. We are working to see if molecular markers will work for quantitative and more complicated traits such as drought. A Maize Program scientist is coordinator of the Insect Resistant Maize for Africa project (IRMA), an effort to develop insect resistant maize for African farmers through conventional and biotechnology applications. Maize staff are also participating in a drought tolerance genomics project, as well as in the fingerprinting of key CIMMYT maize germplasm. The Program has followed progress in research at a CIMMYT on apomixis. Perhaps the 2000 Plant Breeding Review panel of TAC best summarized Program collaboration with the ABC: “Progress in moving biotechnology intomaize br eeding programs is on the right track, and it is expected that in the next years it will provesuccessful.”

Collaboration with our partners. We are working with many more partners now. Increases in the number of trial and seed shipments clearly indicates that collaboration has increased significantly with

[11] Hartkamp, A.D., J.W. White, A. Rodríguez Aguilar, M. Bänziger, G. Srinivasan, G. Granados, and J. Crossa. 2000. *Maize Production Environments Revisited: A GIS-based Approach.* Mexico, D.F.: CIMMYT.

public and private partners. Advanced research institutes with which we share research activities include Iowa State University, the University of Wisconsin, the University of Hannover, the University of Piracicaba, the University of Guelph. We are working more closely with a range of non-governmental organizations in Africa, Nepal, and Bangladesh, as well as promoting collaboration among NGOs themselves.

Work with the private sector has increased significantly, and we continue to seek ways to enhance this collaboration, especially with small national and regional companies. Private companies now comprise the number-one user of CIMMYT maize germplasm in Latin America and use of our materials by private companies has increased in Asia and Africa.

Regarding stronger national programs, we participate in 11 collaborative research projects in which we leverage resources of such organizations. The Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) is our major partner in soil acidity research in South America. We have benefited from support from India, Brazil, and China in training. Nonetheless, we clearly need to do more.

Conclusion

When we reflect back on where we were a few years ago, there is convincing evidence of solid progress in meeting the challenges the Program faced. A key component for continued success will be obtaining secure funding for the activities described in this publication and the other important work the Program conducts. In 2001 Program staff will actively seek support for efforts such as the Africa Maize Stress project, work to disseminate quality protein maize, and sustainable seed production systems for small-scale farmers in Africa, to name a few. This will involve renewing relationships with traditional donors and helping them make the case to their constituencies for continued investment in agricultural research. However, we will also try to identify and bring on-board new contributors from categories such as philanthropic foundations and the private sector. Given the challenges in today's funding environment, we need to convey to responsible individuals in these and other agencies a clear impression of the circumstances faced today by small-scale, resource-poor maize farmersin developing countries. This in turn must be followed up with effective proposals and other information about ways we can work together toward shared goals, in benefit of developing country farmers and consumers
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