Latin American Maize Germplasm Conservation:

Regeneration, In situ Conservation, Core Subsets, and Prebreeding

Proceedings of a Workshop
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CIMMYT® (www.cimmyt.org) is an internationally funded, not-for-profit organization that conducts research and training related to maize and wheat throughout the developing world. Drawing on strong science and effective partnerships, CIMMYT works to create, share, and use knowledge and technology to increase food security, improve the productivity and profitability of farming systems, and sustain natural resources. Financial support for CIMMYT's work comes from many sources, including the members of the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org), national governments, foundations, development banks, and other public and private agencies.

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Abstract: This publication describes progress in collaborative efforts to document, characterize, regenerate, and conserve (both in seed banks and on-farm in situ) maize seed collections from the Americas since 1998. Participants from North, Central, and South America took part in a workshop at the International Maize and Wheat Improvement Center (CIMMYT) from 7-10 April, 2003, to discuss these issues as well as those related to core subsets and prebreeding for maize. Topics covered included: the growth of CIMMYT's maize collection through the Cooperative Regeneration Project; core subsets and prebreeding; conservation and use of local maize races in Oaxaca and Chihuahua; kernel characteristics and tortilla making quality of maize accessions from Mexico, the Caribbean, South and Central America; and enhancement of farmers' varieties using an example from Coahuila, Mexico. Status reports on collections held in 12 countries in the region are provided.

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Contents

Foreword

To the ancient Mayan, maize was life itself. Inextricably linked to Latin America, it was this crop that allowed the Mayan society to evolve from a group of hunter-gatherers to a highly advanced civilization, and today maize still gives life and livelihoods to millions worldwide. The Latin American Maize Germplasm Conservation project aims to conserve and regenerate this lifeblood of America's harvests. The project, supported by USDA, Japan, USAID, and the World Bank, arose in the early 1990s to address the alarming possibility of losing unique collections of farmer varieties of maize forever. Besides representing an important heritage, the seed of these so-called "landraces" constitutes a vital reservoir of traits that breeders can use to improve maize and farmers can use as insurance against crop disease. CIMMYT and partners now conserve seed collections for an estimated 80% of all Latin American maize diversity, including many varieties no longer sown by farmers. Keeping the collections alive and available is a huge and costly job, among other things because seed loses its ability to germinate and requires constant replacement.

By collaborating with national gene banks and the National Center for Genetic Resources Preservation Center (NCGRP), CIMMYT is better able to fulfill its obligations of conserving its collections in trust for humanity, under a 1994 agreement with the United Nations Food and Agriculture Organization (FAO). This special collaborative project with the strong in-kind support of the national gene banks extends the work of the 1990s—an effort that has lived through over a decade of challenges and meager operating budgets for Latin American gene banks.

Inside this book you will find reports from 12 Latin American countries, as well as 6 other reports on the state of maize in Mexico. These accounts give a glimpse into this important work and its most recent accomplishments. To begin with, more than 10,000 seed collections have been rescued, regenerated, stored, and backed up. Through the agronomic trials, extensive data on key traits of collections have been recorded and are available to researchers who seek particular varieties or traits. Finally, a region-wide network of partners has emerged, among whom information, seed, and knowledge are freely shared. No small accomplishment, given the gravity of the situation prior to this effort.

We hope the information herein is useful and look forward to any questions and comments. Mostly, we hope to enjoy your continued support for conserving and using maize genetic resources to benefit farmers and consumers in developing countries, in fulfillment of CIMMYT's mission.

Masa Iwanaga
Director General
International Maize and Wheat Improvement Center
March 2005

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The Growth of CIMMYT's Maize Collection with the Introduction of Latin American Maize Landrace Accessions through the Cooperative Regeneration Project

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Abstract

Latin American maize landraces are globally the most important maize genetic resources and should be conserved for current and future generations. For more than 60 years, the International Maize and Wheat Improvement Center (CIMMYT) and its predecessor institutions have been conserving and using these genetic resources for maize improvement. In order to safeguard the original diversity of maize races found in the region, the Latin American maize landrace conservation network of national and international maize banks in the Americas has regenerated and conserved nearly 10,000 accessions over the last 10 years. The national banks have conserved their own regenerated accessions and deposited the duplicates at CIMMYT and at the USDA's National Center for Genetic Resources Preservation (NCGRP) at Fort Collins, Colorado, USA. The CIMMYT maize collection has enlarged to 24,463 accessions, including its recent acquisitions. It now holds 21,767 Latin American maize germplasm accessions from South and Central America, including Mexico and the Caribbean region.

Maize Landrace Collection in Latin America

Maize genetic resources consist of maize landrace accessions, wild relatives (teosinte and *Tripsacum* spp.), inbred lines, populations, and gene pools. Latin American maize landrace accessions are the most valuable renewable genetic resources available to maize breeders and research scientists worldwide. It is imperative to conserve these genetic resources to allow continued genetic gains to be made through breeding as well as to broaden the genetic base of cultivars tolerant to biotic and abiotic stresses. Maize evolved in Mesoamerica (Mexico and part of Central America) and has spread to the rest of the Americas and to other continents over the last several hundred years. Latin American maize landrace accessions have been classified by race (see Taba in these proceedings; Goodman and Brown 1988). These races are expected to express the genetic wealth of the species (*Zea mays* L.) as evidenced from their origins and evolution (Wilkes 2004). The objective of the ongoing project to regenerate Latin American maize germplasm preserved at the national genebanks, as well as at CIMMYT and NCGRP, is to secure safety duplicates in long-term seed storage at CIMMYT and NCGRP as well as in medium- and long-term seed storage in the national maize genebanks. The regenerated germplasm accessions have become the designated germplasm in the in-trust collection under the 1994 FAO-CIMMYT agreement and will be conserved under the International Treaty for Plant Genetic Resources for Food and Agriculture.

The CIMMYT Maize Collection: A Historical Overview

The CIMMYT maize bank started with landrace accessions collected by the joint Rockefeller Foundation-Government of Mexico program, Office of Special Studies (OEE) in 1943, to improve productivity of basic food crops in Mexico. By 1947 the Mexican maize collection was about 2,000 accessions. CIMMYT's predecessor institutions (OEE and the Inter-American maize program) extensively collected maize landraces in Mexico, Central America, and the Caribbean and also introduced maize germplasm accessions from other countries, through germplasm exchanges until the early 1960s. From 1967 through the 1980s, the CIMMYT maize bank regenerated and incorporated a large part of the additional landrace accessions received from NSSL, Fort Collins, Colorado, USA. These additional accessions originated from the project established in the 1950s by the National Academy of Sciences (NAS) and National Research Council (NAS-NRC), USA, which collected and studied Latin American and Caribbean maize landraces and preserved them for future use. The project was directed by a committee of geneticists, maize breeders, botanists, and administrators and produced a series of bulletins on races of maize (Goodman and Brown 1988). The catalogs, Collections of Original Strains of Corn I and II (NAS-NRC 1954 and 1955), listed 10,922 samples, some of which (7,629 samples of Brazil and Colombia regional banks) were transferred to CIMMYT in 1967.

In 1973, CIMMYT transferred all Colombian samples (1,785) to the Colombian bank. Part of the highland accessions of the Andean region went to Peru for a seed regeneration project with the National Agrarian University, La Molina, Lima. Meanwhile, CIMMYT continued to regenerate as many accessions as possible and incorporated them into the bank (Gutiérrez 1974). There was a time in the mid-1970s through 1980 during which the germplasm bank concentrated largely on seed regeneration, maintenance, and distribution.

In 1982-1984, Pioneer Hi-Bred International Inc. regenerated 300 CIMMYT accessions each year at Homestead, Florida, USA (Salhuana 1984). The number of bank accessions reached about 9,800 in 1980 and by the end of 1990 was up to 10,360 (Pardey et al. 2001). This was accompanied by advanced computing technology and a new awareness of crop genetic resource conservation in the CGIAR and the FAO International in 1986. Undertaking on Plant Genetic Resources (1983), CIMMYT launched new genetic resources initiatives on maize and wheat. It held a global workshop on maize germplasm conservation and utilization (Russell and Listman 1988). CIMMYT compiled passport information for the accessions from the catalogs of Collections of Original Strains of Corn I and II (NAS-NRC 1954 and 1955) and also from the original collection sheets that were available in the bank archives (Taba 1988). During a global workshop, Goodman and Holley (1988) advocated the need for an international cooperation for regeneration of germplasm among the Latin American maize banks, evaluation and prebreeding, and an appropriately equipped, high elevation, frost-free experimental station where the many accessions that were being lost in maize germplasm banks throughout Latin America could be successfully increased. An active maize crop network for conserving landrace germplasm was proposed by Anishetty (1988). CIMMYT, assisted by the ex situ network of FAO, has focused its mandate on conservation of maize landraces in the Western Hemisphere.

In the 1970-80s, the national banks in Latin America collected new samples representing national maize diversity supported by the International Board on Plant Genetic Resources (IBPGR) or the national banks' own funds. Prompted by the results of the Latin American Maize Project (LAMP) (Salhuana et al. 1991), CIMMYT held a workshop of Latin American maize bank managers in 1992 and since 1993 has coordinated a cooperative regeneration project (CRP) to rescue and preserve national genebank accessions, with financial help given by USDA-NCGRP/USAID. This cooperative project has led to substantial increases in the number of CIMMYT maize accessions. Eberhart (1988) reported that the number of maize germplasm accessions from Central and South America at NSSL in 1988 was about 11,000, out of a total 17,000. The Latin American maize germplasm collection in NCGRP has received an additional 10,000 samples of CIMMYT backup collection through the cooperative project.

CIMMYT conserves and reinforces maize landrace diversity from Latin America while introducing representative accessions from other continents. The latter group has grown to more than 1,000 accessions through germplasm exchanges and nearly half of them have been regenerated and registered as accessions in the CIMMYT collection. CIMMYT preserves maize germplasm from 64 countries (19 in Latin America, 19 in the Caribbean, 11 in Africa, 10 in Asia, 3 in Europe, and 2 in Oceania).

The current cooperative regeneration project to rescue Latin American maize germplasm accessions has played a significant role in assembling Latin American maize landrace diversity and making it available for breeders and research scientists worldwide. However, there are still gaps in CIMMYT's Latin American maize collection. These gaps can be filled by continuously working with collaborators from the following countries: Argentina, Chile, Colombia, Bolivia, Brazil, Belize, Guatemala, Costa Rica, Ecuador, Guiana, Mexico, Paraguay, Peru, Surinam, and Venezuela. CIMMYT did not have cooperative regeneration projects with countries in the Caribbean, except Cuba. Further collection of intra-racial diversity in Latin America continues for on-farm conservation (Aragón et al. in these proceedings). The newly collected accessions are evaluated on-farm in situ, and the evaluation data are compiled in the bank's database.

Specifically-adapted Latin American highland maize accessions at CIMMYT and NCGRP that have been stored for 20-30 years without regeneration are in need of regeneration. They must be grown in environments where they were collected. Continued collaboration with Latin American maize banks is envisioned for regenerating these maize races.

The CIMMYT maize collection also includes inbred lines, populations, and gene pools from the CIMMYT breeding and prebreeding programs, as well as teosinte and *Tripsacum* accessions. Teosinte accessions are regenerated in isolation or monitored in situ with the national banks of Mexico and Guatemala. *Tripsacum* accessions are planted at CIMMYT's Tlaltizapán field station.

The Cooperative Regeneration Project in Latin America

The last project summary from the Latin American maize germplasm conservation network was reported in a workshop proceedings held at CIMMYT in 1998 (Russell and Listman 1988). The cooperative project has been in progress since 1993, and its last cooperators' meeting was held in April 2003. The network has been supported by USAID, USDA-NCGRP, and CIMMYT, and by core funds from Japan, Mexico, and the European Union (EU). The current cooperating countries of Argentina, Bolivia, Brazil, Ecuador, Guatemala, Mexico, Peru, and Venezuela signed memorandums of understanding (MOUs) and contracts for the regeneration project with CIMMYT for the period from 1998 to 2003. The principal investigators (PIs) of the project share a sense of urgency for conserving the maize landrace accessions, and without the initiative of the cooperating national genebanks in Latin America to rescue and preserve the maize landrace accessions in their collections the cooperative network would not have been possible.

In 1996, CIMMYT constructed a new seed storage facility and stored the accessions regenerated by the PIs. Duplicate seed accessions were sent to NCGRP either by direct shipments from the PIs or via CIMMYT. From April 2003, for three years, the cooperative network has also received additional support through the Genebank Upgrading Project from the World Bank to safeguard in-trust collections of the CGIAR centers.

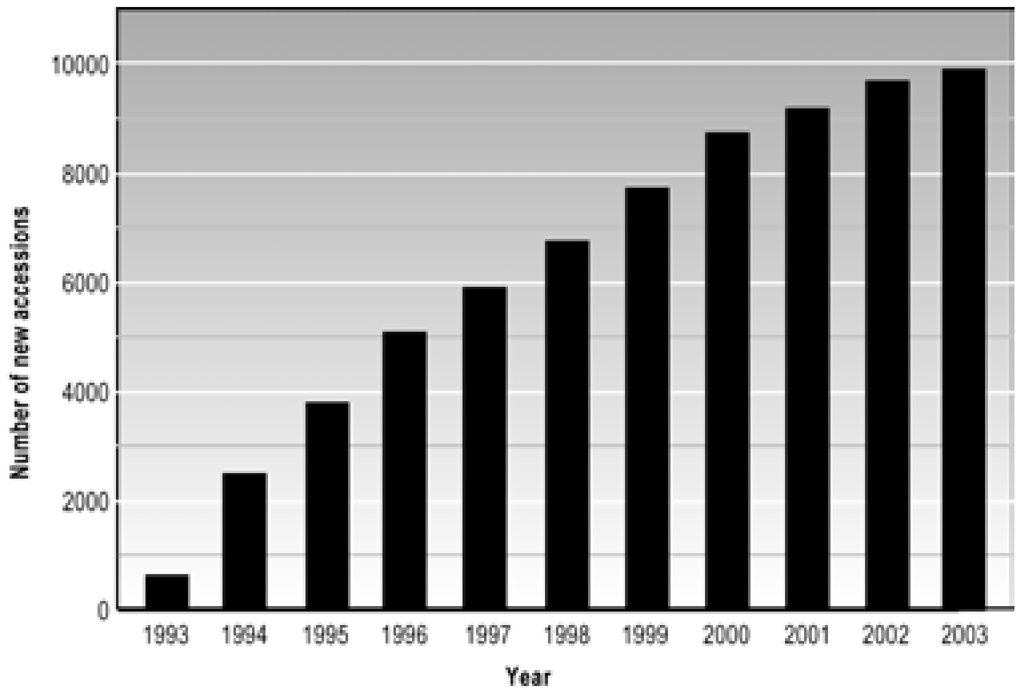
The regeneration protocol has remained unchanged since the beginning of the project. For each 100 or more full-sib ears regenerated per accession, at least 3 kg of balanced bulks are made for long-term conservation at CIMMYT and NCGRP, which receive 1.5-3 kg each. The cooperators have done their best in regenerating the seed accessions, but sometimes the accessions had to be replanted one or two times to obtain enough ears. CIMMYT captured passport information and regeneration data made available by the cooperators. Argentina, Bolivia, and Ecuador have published catalogs of their bank accession data.

The results of the cooperative project are summarized in Table 1 and Figure 1. Regeneration priority lists were developed by the cooperators to try to prevent duplicating accessions already in CIMMYT/NCGRP collection. In the period of 1993-2003, the number of samples received at CIMMYT and NCGRP totaled 16,365, of which 9,976 samples were new unique introductions to the CIMMYT maize collection (Table 1). CIMMYT has placed 22,144 accessions under the FAO-CIMMYT designated accessions agreement, which includes all Latin American introductions through the cooperative project. The current number of CIMMYT accessions from Latin America, including Mexico and the Caribbean, is 21,767, which is about 80% of estimated total number of Latin American maize germplasm accessions (Taba and Eberhart 1999).

Table 1. Numbers of accessions received from the cooperating countries and new introductions to the CIMMYT maize collection, 1993-2003.

Country	No. of samples received	CIMMYT new accessions
Argentina	896	758
Bolivia	579	473
Brazil	658	569
Chile	416	298
Colombia	1491	1001
Cuba	101	101
Ecuador	1065	252
Guatemala	304	97
Honduras	42	42
Mexico	9116	4939
Paraguay	440	439
Peru	1073	856
Venezuela	184	151
TOTAL	16365	9976

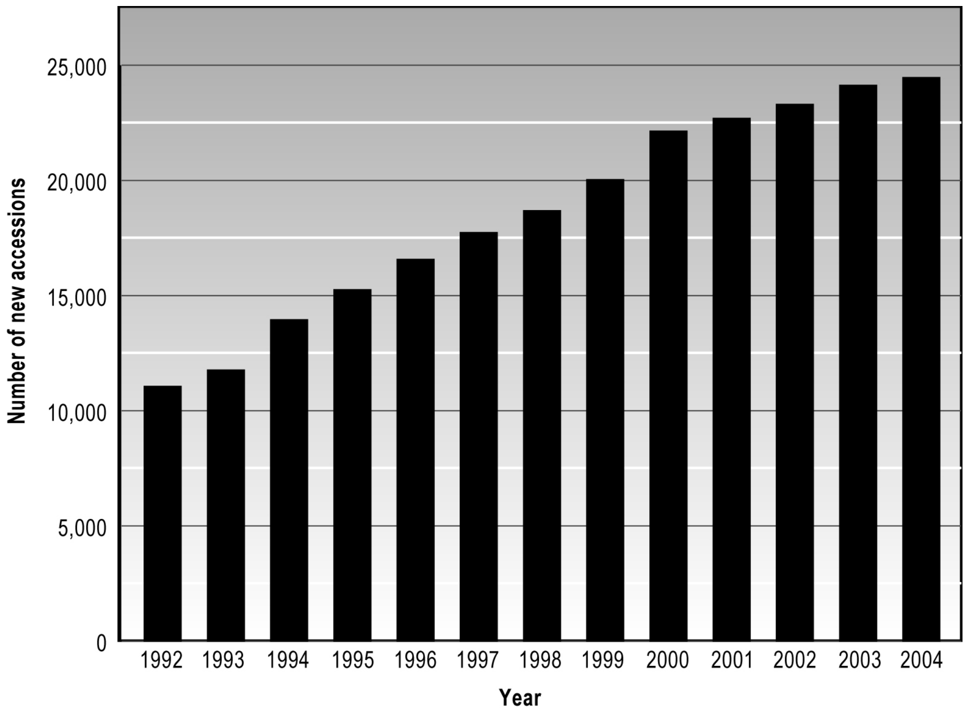
Figure 1. The increase of Latin American maize germplasm accessions at CIMMYT through the cooperative project, 1993-2003.



Active and Base CIMMYT Maize Collections

The seed storage facility at CIMMYT is a two-storey, fortified, concrete bank that houses both maize and wheat collections. For each crop collection, $400m^3$ space is allocated both to the active collection at -3^oC and to the base collection at -18^oC, with storage at ground level and below ground level, respectively. The relative humidity for the active collection is maintained at 25% RH. Four-liter plastic, airtight containers (2-3 kg of seeds) are used for storing the active maize collection, and heat-sealed aluminum foil bags (1-2 kg of seeds) are used for the base collection. Core subset accessions are designated in the evaluation trials and are preferentially conserved in the active collection and preserved in the base collection. Figure 2 shows annual increases in the CIMMYT maize collection since 1992. The CIMMYT maize collection reached 24,463 accessions as of June 2004, from 11,062 in 1992. The new introductions (9,976 accessions in Table 1) from the cooperative project, accounted for 74.4% of the new germplasm acquisitions in 1993-2003. The second largest addition (2,075) to the CIMMYT maize collection (15.5%) has been from CIMMYT maize lines, varieties, populations, and gene pools. The remainder (1,350 accessions) is from NAS-NRC collections or introductions from other regions that were regenerated at CIMMYT.

Figure 2. Annual increase of CIMMYT maize bank holdings, 1992-June 2004.



Latin American Maize Landrace Conservation Network

The seed accessions collected by the NAS-NRC project were preserved at the regional seed banks at Medellin, Colombia and Chapingo, Mexico in cooperation with the Rockefeller Foundation. The bank in Piracicaba, Brazil in cooperation with the University of Sao Paulo also contributed to this preservation. In the 1950s and early 1960s, small duplicate seed samples from these regional seed banks were sent first to Glen Dale, Maryland, USDA, and later transferred to NSSL at Fort Collins, Colorado. In the mid-1960s, these duplicate samples from the Andean region and southern part of South America, with some exceptions, were transferred from NSSL to CIMMYT for regeneration. Using the collections preserved at Chapingo, Mexican, Central American and Caribbean collections were also grown out at CIMMYT (Gutierrez 1974; Wellhausen 1988). These regenerated samples were stored in the former CIMMYT maize bank facility when it was constructed at El Batán in 1973. Andean materials were sent to Colombia and Peru for regeneration as mentioned above. The accessions regenerated in Peru were received at CIMMYT in the mid-1970s. In the mid-1960s through the mid-1970s, CIMMYT regenerated the other part of the NAS-NRC collections as well as its own collections from the predecessor institutions (OEE and Inter-American maize program) and deposited them at NSSL with their corresponding PI numbers (Plant Introduction number, USDA). In 1973, the NAS-NRC maize germplasm resources committee recommended that CIMMYT safeguard them in long-term seed storage at NSSL.

When the cooperative project to rescue Latin American maize germplasm accessions was launched in 1993, the regenerated seed accessions were sent to CIMMYT and NSSL for long-term preservation under the MOU and contracts with the cooperator institutions in the thirteen countries (Table 1). CIMMYT and NCGRP-USDA have also exchanged an MOU for the safety duplication of the CIMMYT maize collection at NCGRP. All accessions are preserved in the long-term seed storage facilities at NCGRP, with CIMMYT maize bank identification numbers. Including the accessions with PI numbers that CIMMYT sent to NSSL in the 1970s-1980s as safety duplicates, the current number of duplicate accessions of the CIMMYT maize collection at NCGRP is 20,041, which is 81.92% of the entire CIMMYT maize collection. The composition of the duplicated accessions at NCGRP is landrace accessions (19,526), composites (207), varieties (186), and gene pools (122).

The Latin American maize germplasm conservation network is a continuation of the coordinated work of LAMP, which evaluated the maize germplasm accessions of 11 Latin American and United States national maize banks and chose elite accessions for enhancement in 1985-1995 (Salhuana et al. 1997). The CIMMYT maize bank organized a series of workshops to keep the network updated on the progress of the cooperative project for the ten-year period. It is the cooperators or the PIs of the cooperative project that have regenerated and provided duplicates of nearly 10,000 Latin American landrace accessions at CIMMYT and NCGRP.

The network responsible for conserving maize germplasm in Latin America has already regenerated accessions, representing the vast majority of the maize landrace diversity of the region. The same network will be key for the maintenance and availability of these germplasm accessions in the future and can be extended to germplasm enhancement (prebreeding) in the region. The network can cover not only germplasm enhancement for the breeders but also for the farmers who cultivate and conserve the local races of maize on-farm in situ for food security.

Acknowledgements

The authors are grateful to the cooperators of the projects for their tireless efforts to rescue Latin American maize landrace accessions and to the other members of the Latin American maize germplasm conservation network.

References

Anishetty, N.M. 1988. Active collections network: A proposal for maize germplasm conservation and use. In N.Russell and G.M.Listman (eds.), *Recent advances in the conservation and utilization of genetic resources: Proceedings of the global maize germplasm workshop*. Mexico, D.F.: CIMMYT. pp.99-105

Eberhart, S. 1988. Long-term storage of plant germplasm. In N.Russell and G.M.Listman (eds.), *Recent advances in the conservation and utilization of genetic resources: Proceedings of the global maize germplasm workshop*. Mexico, D.F.: CIMMYT. pp. 49-51.

Gutiérrez, G. M. 1974. Maize germplasm preservation and utilization at CIMMYT. In *Proceedings Worldwide Maize Improvement in the 1970s and the Role for CIMMYT*. El Batán, Mexico. Chap. 4:1-21.

Goodman, M.M., and W.L. Brown. 1988. Races of corn. In G.F. Sprague and J.W. Dudley (eds), *Corn and Corn Improvement*. Agronomy Monograph no. 18, 3rd edition. ASA-CSSA-SSA, 677 South Segoe Road, Madison, WI 53711, USA. pp. 33-80.

Goodman, M.M., and R.N. Holley.1988. US maize germplasm: Origins, Limitation, and Alternatives. In N.Russell and G.M.Listman (eds.), *Recent advances in the conservation and utilization of genetic resources: Proceedings of the global maize germplasm workshop*. Mexico, D.F.: CIMMYT. pp. 130-148.

NAS-NRC. 1954. Collections of original strains of corn I. Report of the committee on preservation of indigenous strains of maize. Division of Biology and Agriculture, Agricultural Board, Washington, D.C. USA. pp.1-300.

NAS-NRC. 1955. Collections of original strains of corn II. Report of the committee on preservation of indigenous strains of maize. Division of Biology and Agriculture, Agricultural Board, Washington, D.C. USA. pp. 301-592.

Pardey, G. P., B. Koo, B. D. Wright, M.E. Van Dusen, B. Skovmand, and S. Taba. 2001. Costing the conservation of genetic resources: CIMMYT's ex situ maize and wheat collection. *Crop Sci*. 41:1286-1299.

Russell, N., and G.M. Listman (eds.). 1988. Recent Advances in the Conservation and Utilization of Genetic Resources: Proceedings of the Global Maize Germplasm Workshop. Mexico, D.F.: CIMMYT.

Salhuana, W. 1984. Information of the CIMMYT accessions grown by Pioneer Hi-Bred International, Inc. at Homestead, Florida. Internal document, Pioneer International Hi-Bred Inc. USA.

Salhuana, W., Q. Jones, and R. Sevilla. 1991. The Latin American Maize Project: model for rescue and use of irreplaceable germplasm. *Diversity*. 7, nos.1&2: 40-41. Washington, DC.

Salhuana, W., R. Sevilla, and S.A. Eberhart (eds.). 1997. Final report: LAMP. ARS Special Publication, Beltsville.

Taba, S. 1988. User oriented bank management. In N.Russell and G.M.Listman (eds.), *Recent advances in the conservation and utilization of genetic resources: Proceedings of the global maize germplasm workshop*. Mexico, D.F.: CIMMYT. pp. 39-48.

Taba, S., and S. Eberhart. 1999. The status of Latin American maize germplasm conservation. In Latin American maize germplasm conservation: Core subset development and regeneration: Proceedings of a workshop held at CIMMYT, June 1-5, 1998. CIMMYT, Mexico, D.F. pp. 1-5.

Wellhausen, E.J. 1988. The indigenous maize germplasm complexes of Mexico: Twenty-five years of experience and accomplishments in their identification, evaluation, and utilization. In N.Russell and G.M.Listman (eds.), *Recent advances in the conservation and utilization of genetic resources: Proceedings of the global maize germplasm workshop*. Mexico, D.F.: CIMMYT. pp. 17-28.

Wilkes, G. 2004. Corn, strange and marvelous: But is it's definitive origin known? In C. W. Smith, J. Betran, E.C.A. Range (eds.), *Corn: origin, history, technology, and production*. John Wiley & Sons, Inc. New York. pp. 3-64.

Preliminary Breeder Core Subsets and Prebreeding

Suketoshi Taba

CIMMYT's Maize Collection

The CIMMYT maize germplasm bank preserves more than 21,000 landrace accessions from the Americas and about 2,000 accessions from breeding programs. The bank collection started in 1947 with about 2,000 Mexican landrace samples, assembled by a joint program between the Rockefeller Foundation and the Government of Mexico to improve the productivity of basic food crops in Mexico. Following this early study of maize diversity in Mexico, the Ministries of Agriculture in Latin America, US National Academy of Science-National Research Council (NAS-NRC), and the Rockefeller Foundation collected Latin American maize landraces in the 1940s and 1950s. Passport data was compiled from this so-called NAS-NRC collection, and the catalogs were published in 1954-55. CIMMYT has inherited part of these samples and has preserved as many of them as possible, following their introduction from collaborating maize banks since CIMMYT was established in 1966. Recent introductions to CIMMYT's bank have included materials from additional collections that were made by the International Board for Plant Genetic Resources (IBPGR) (now the International Plant Genetic Resources Institute, IPGRI) and the national program initiatives in Latin American. The Latin American maize landrace regeneration project, coordinated by CIMMYT and supported by USDA and partly by USAID since 1992, has resulted in the current size of CIMMYT's collection (Pardey et al. 2001; Taba and Eberhart 1998; Taba et al. in this proceedings). The size of the collection will increase with more introductions in the near future to fill some of the gaps in the collection. The Latin American maize landrace collection is the most important primary gene pool of a major crop and can provide useful genetic diversity for maize improvement worldwide. The active cooperator network in Latin America, responsible for conserving the germplasm collection, needs continued support and collaboration.

Evaluation of the Accessions and Collection Management

The NAS-NRC collection has been widely distributed and used in maize producing areas in many parts of the world. Using this germplasm, CIMMYT has developed enhanced maize germplasm pools, populations, and inbred lines. However, systematic characterization and evaluation of the field performance of germplasm from this collection has not been fully documented. Current information from field evaluations has been published on a CD-ROM (Taba et al. 2003) and provides the germplasm users with agro-morphological data and information on phenotypic diversity among maize races grown in CIMMYT's experimental stations.

The field evaluation data on the CD-ROM have been compiled on Mexican dent, Caribbean flint and dent, Cateto and related races, and Brazilian dent and flint races, but do not include Andean or Central American highland races. In order to complete the performance data for Andean and Central American highland races, and others that are adapted to in situ on-farm conditions in Latin America (Taba 1995, 1997, 1998b) and elsewhere, on-farm evaluations should be planned and conducted with our cooperators in Latin America.

Using agro-morphological data, accessions were grouped by multivariate analysis for classification and ordination. Breeder core subsets (20%) that best represent each of the homogeneous groups (clusters) are chosen by a selection index based on yield, grain moisture, and ear quality, and by an agronomic performance rating. Core subsets representing the germplasm collection should facilitate collection management and use (Brown 1989, 1995; Brown and Spillane 1999). Preliminary breeder core subsets, representing phenotypic diversity for a number of agro-morphological traits, can be used as a management tool for maize breeders and research scientists. Such core subsets should facilitate decision-making while choosing the most appropriate seed to meet seed requests and for enhancing breeding populations through the best use of materials for prebreeding. Breeder core subsets are particularly helpful when no information is available for probable sources of the traits of interest, such as a source of resistance to a new pathogen strain or a new pest biotype.

Intra-racial and Intra-regional Diversity Assessed by Multivariate Cluster Analysis

Primary and secondary race classifications of the bank passport data were carried out. Originally, maize race names were described in NAS-NRC's race bulletins (Goodman and Brown 1988). Most often, however, landrace collections did not fit typical maize race descriptions. An accession is classified by recognizing the primary and secondary races that could have formed it. For the accessions described in the maize race bulletins of NAS-NRC, we have recorded them with purity level "9" (typical race collection) together with the name of the race in the passport data. The accessions with similar geographic origins or adaptation were also evaluated in trials whereby intra-racial or intra-regional diversity was identified.

Agro-morphological traits that were recorded are days to anthesis (AN), days to silking (SI), plant height in cm (PH), ear height in cm (EH), seed moisture % (MO) at harvest, tillers per plant (TI), ear length in cm (EL), ear diameter in cm (ED), kernel length in cm (KL), kernel width in cm (EW), kernel row number (KRN), shelling % (SH), ears per plant (EP), leaf senescence (LS), and number of days from silking to ear leaf senescence. Yield (Y), root lodging (RG), shoot lodging (SG) or standability, and ear rot % (ER) were not included in the multivariate cluster analysis. Instead, they were used for constructing the selection index, which allows identification of the accessions within the cluster having the best agronomic performance. Seed moisture (%) was used for both cluster analysis and construction of a selection index.

Multivariate cluster analysis was applied to data of the individual and/or combined trials. The entries were tabulated within clusters formed by the multivariate cluster analysis. In the analysis employed in this study, the Ward method was used for obtaining the initial groups, and the likelihood-based approach of Normix was utilized for improving those groups (Franco et al. 1997). The analysis was performed using CLUSTAN software (Wishart 1987). Canonical discriminant analysis was then performed on the groups formed by the Ward-Normix method using SAS (SAS 1996) to display the variability between subgroups explained by the canonical variables. In some cases, Mahalanobis distance was calculated to determine average distances among cluster centroids (Mahalanobis 1930). Presence of intra-racial or intra-regional diversity can be indicated between and among the clusters formed by the multivariate cluster analysis (Franco et al.1997; Taba 1995, 1997; Taba et al. 1994, 1998 a and b; Crossa et al.1995).

Development of Preliminary Core Subsets and Their Use in Prebreeding

Preliminary core subsets (the best 20% of the accessions from each of the non-overlapping clusters that are formed by the multivariate cluster analysis) are chosen by selecting accessions with high selection index values and agronomic performance ratings and by specific variations observed in the accession.

We have chosen preliminary core subsets (20%) to indicate probable useful variations present in the germplasm collections. Genotype by environment (G x E) interactions have not been adequately taken into account when choosing core subsets. Trials were evaluated in a limited number of environments (mostly at CIMMYT's experimental stations) with two replications. Some trials were conducted in many environments and a core subset was chosen using the data from the combined analysis. Preliminary core subsets include a wide spectrum of diversity within a race or race complex. In 2002, we had 7,762 unique accessions evaluated in a varying numbers of trials, and we will evaluate more accessions in the future using the same protocol.

Preliminary core subsets should be useful to breeders and research scientists for screening useful genetic diversity in a cost-effective manner. Caribbean core subsets (Taba et al. 1998b) were testcrossed with heterotic tester lines to evaluate combining ability of the accessions, and the best breeding crosses were further evaluated as donor germplasm sources with allelic diversity for high grain yield. CIMMYT's heterotic gene pools can be enhanced using the core subsets through prebreeding.

CIMMYT Maize Gene Pools and Prebreeding

Original landrace accessions are characterized by poor agronomic performance, such as taller plant and ear heights, late maturity, and poor standability. Their direct use in the modern farming system is limited, except when they are well adapted to grow at particular sites, where farmers maintain them in situ. CIMMYT maize gene pools have been developed and improved since the mid 1970s and have provided tropical maize breeders with useful diversity for the desired plant and ear types for population, line, and hybrid development. The role of these gene pools is to capture the useful genetic diversity that exists in the landrace accessions and to foster genetic recombination in the gene pool to obtain superior enhanced genotypes. Over the last few decades, superior lines and hybrids have been developed with desirable plant types, maturity, and good standability. A new challenge that maize breeders face is to further enhance the performance of current elite lines and hybrids. Enhancement of CIMMYT gene pools is desirable to meet the need of current and future breeders who focus on development of high yielding hybrids. On the other hand, enhancement of these gene pools can also help farmers who cultivate and improve their maize races for traits such as grain quality. Superior genotypes from the gene pools can be used to enhance the local races' agronomic traits such as standability, yield potential, and grain quality. The goal of prebreeding is to enhance both the agronomic performance and the combining ability of flint and dent pools as heterotic partners of the same ecology, maturity, and grain color. Another is to enhance and monitor the performance of local maize races grown by farmers who conserve unique maize diversity in situ.

Accessions' evaluations, development and further evaluation of core subsets, germplasm enhancement, and introgression and accumulation of useful alleles in the gene pools are the systematic approaches taken to exploit CIMMYT's germplasm collection. The first three steps concern evaluations of the accessions and the last two are prebreeding steps. Germplasm enhancement utilizes 75% of elite sources and 25% of promising breeder core accessions to develop breeding crosses. For example, we identified 100 Caribbean accessions from evaluation trials conducted at CIMMYT in the early 1990s. The test crosses with CML 413 (heterotic pattern B) and CML 287 (heterotic pattern A) measured the combining ability of the accessions. To improve plant type, maturity, and lodging, selected breeding crosses were crossed with another line of the same heterotic pattern. Then S_2 lines were generated in the breeding crosses (25% of the original accession and 75% elite germplasm with the same heterotic pattern) for evaluation of combining ability with the opposite heterotic line and desired agronomic traits. The best S_2 lines or S_3 bulks from the germplasm enhancement program will be introgressed into the gene pool (in this case, pool 25 tropical late flint and 26 tropical late dent) as their performance is equal to or better than those of the corresponding gene pool.

The heterotic gene pools are improved by S_2 reciprocal recurrent selection. Useful genes and alleles that are present in the gene pool and introgressed through germplasm enhancement are accumulated in the ongoing recurrent selection cycles. The best S_2 lines or S_3 bulks are then available to breeders. Prebreeding is involved in developing materials for improved drought stress, insect resistance, nitrogen use efficiency, and value-added traits in progeny selection. Prebreeding activities can also be carried out for improvement of special grain types such as floury, sugary, morocho, and popcorn. Current CIMMYT gene pools are: pools 1 and 2 (early white highland), pools 3 and 4 (early yellow highland), pools 5 and 6 (late white highland), pools 7 and 8 (late yellow highland), pools 9 and 10 (late white mid altitude transition), pools 11 and 12 (late yellow mid altitude transition), pools 15 and 16 (early white tropical), pools 17 and 18 (early yellow tropical), pools 19 and 20 (intermediate white tropical), pools 21 and 22 (intermediate yellow tropical), pools 23 and 24 (late white tropical), pools 25 and 26 (late yellow tropical), pools 27 and 28 (early white subtropical), pools 29 and 30 (early yellow subtropical), pools 31 and 32 (intermediate white subtropical), and pools 33 and 34 (intermediate yellow subtropical).

Race Names

Race names used in accessions' evaluation include local or common names, as well as the maize race descriptions used in the race bulletins (publications on races of maize in Mexico, Central America and the Caribbean, and South America include: Wellhausen et al. 1952, 1957; Brieger et al. 1958; Brown 1953; Grobman et al. 1961; Grant et al. 1963; Hatheway 1957; Roberts et al. 1957; Timothy et al. 1961; NAS-NRC 1954, 1955). In addition, Paterniani and Goodman (1977) described races in Brazil and adjacent areas. Classification of landraces in the Americas started with the concept of race that Anderson and Cutler (1942) proposed, which recognized common features for describing a maize race. In the past, CIMMYT compiled records on race classification from bank field books and passport data. In more recent times, CIMMYT compiled the race names or common names of new introductions provided by passport data from the donor institutions. Common names or local names are not necessary to describe new maize races. However, it is useful to recognize the accession with its unique name as an indicator of diversity in Latin American maize races.

Short Race Names	Full Race Names	Short Race Names	Full Race Names
AINTER	Acre Interlocked	BLANDI	Blandito
AJALEA	Ajaleado	BLANSO	Blanco de Sonora
ALAZAN	Alazan	BLASON	Maize blando/harinoso de Sonora
ALEMAN	Aleman	BLJUNI	Blanco de Junio
ALLAJA	Allajara	BOFO	Bofo
ALTIPL	Altiplano	BOLABL	Bola blanca
AM8HIL	Amarillo ocho hilleras	BOLITA	Bolita
AMAGAC	Amagaceño	BRACPP	Brachytic pop corn
AMAHUA	Amarillo Huancabamba	C.PLAT	Central plateau-teosinte
AMANUB	Amarillo de Nuble	CABUYA	Cabuya
AMARIL	Amarillo	CACAHU	Cacahuacintle
AMMALL	Amarillo de Malleco	CACAO	Cacao
ANCASH	Anacashino	CACHCH	Calchaquí Chileno chico
ANCHO	Ancho	CACRCH	Calchaquí cristalino chico
ANDAQU	Andaqui	CAGRCH	Calchaquí Chileno grande
ANDINO	Andino	CAINGA	Cainga
APACHI	Apachito	CALCHA	Calchaqui

APERLA	Aperlado	CALWFT	Calchaqui white flint
ARAGUI	Araguito	CAMELI	Camelia
ARAUCA	Arauca	CANAR8	Canario de ocho
AREQUI	Arequipeño	CANBAY	Canbay
ARGENT	Argentino	CANDEL	Candela
ARIZON	Arizona	CANECH	Capia negro Chileno
ARROAM	Arrocillo amarillo	CANGUI	Canguil
ARROAZ	Arrocillo azul	CANILL	Canilla
ARROBL	Arrocillo blanco	CAPAM8	Capia amarillo de ocho
ARROCI	Arrocillo	CAPIBL	Capia blanca
AVDJAK	Avari' Kjakaira	CAPROS	Capia rosada
AVMORG	Avati' moroti' guapi'	CAPVAR	Capia variegada
AVMORM	Avati' moroti' mita'	CARIAC	Cariaco
AVMORO	Avati' moroti'	CARMEN	Carmen
AVMORT	Avati' moroti' ti'	CATAMA	Cateto amarillo
AVPICH	Avati' pichinga	CATASS	Cateto assis Brasil
AVPIHU	Avati' pichinga ih'u	CATCON	Cateto conico
AYSUMA	Aysuma	CATETO	Cateto
AZUL	Azul	CATFIN	Cateto Paulista fino (also CATPAF)
BALSAS	Balsas-teosinte	CATGRA	Cateto grande
BBLAND	Blanco blandito	CATNPR	Cateto nortista precoce
BENIBL	Beni blando	CATPAF	Cateto Paulista fino (also CATFIN)
BENIDU	Beni duro	CATPAG	Cateto Paulista Grosso
BHDENT	Blanco harinoso dentado	CATSUE	Cateto sulino escuro
BL8HIL	Blanco ocho hileras	CATSUG	Cateto sulino grosso
BLAAYA	Blanco Ayabaca	CATSUL	Cateto sulino
BLACDT	Black dent	CELAYA	Celaya
BLANCO	Blanco	CHAKES	Chake-sara
CHALCO	Chalco	CRIOLL	Criollo
CHALQU	Chalquño	CRISBL	Cristalino blanco
CHANCA	Chancayano	CRISCO	Cristalino cororado
CHANDE	Chandelle	CRISTA	Cristal
CHAPAL	Chapalote	CRLINO	Cristalino
CHAPAR	Chaparreño	CRPERO	Cristal perola
CHARUA	Charua	CRPYPA	Cristal Paraguay paulista
CHAUCH	Chaucho Huandango	CRSEMD	Cristal semi-dentado
CHAVAN	Chavantes	CRSULI	Cristal sulino
CHECCH	Checchi	CSERJA	Complejo serrano de Jalisco
CHILLO	Chillo	CUACAT	Cuarenton Cateto
CHIMLO	Chimlos	CUAREN	Curenton
CHIRIM	Chirimito	CUBAAM	Cuban yellow flint
CHOCLE	Choclero	CUBABL	Cubano blanco
CHOCOC	Chococeño	CUBACO	Cubano corolado
CHOLIT	Cholito	CUBADE	Cuban dent
CHULLP	Chullpi, Peru	CUBANO	Cuban yellow flint/dent (also MCUBAN)
CHULPI	Chullpi, Ecuador	CULLI	Culli
CHUNCH	Chuncho	CURAGR	Curagua grande
CHUNCU	Chuncula , also Chunku	CURAGU	Curagua
CHUSPI	Chuspilla	CUZCO	Cuzco
CHUTGR	Chutucuno Grande	CUZCOE	Cuzco Ecuatoriano
CHUTUC	Chutucuno	CUZCRA	Cuzco cristalino amarillo
CLAVIL	Clavillo	CUZCRI	Cuzco cristalino
CLAVO	Clavo	CUZGIG	Cuzco gigante
COLCAT	Colorado Cateto	DEBLAR	Dentado blanco rugoso
COLORA	Colorado	DENAMA	Dentado amarillo and anaranjado
COMITE	Comiteco	DENBLA	Dentado and semi-dentado blanco

COMTRO	Compuesto Tropical	DENBRA	Dente branco
COMUN	Comun	DENSDB	Dentado and semi-dentado amarillo/blanco
CONCEB	Concebideño	DENTAD	Dentado
CONDEN	Cónico Dentado	DIDECA	Diente de caballo
CONEJO	Conejo	DSDAMF	Dentado and semi-dentado amarillo marlo fino
CONICO	Cónico	DTRGLI	Dente Riograndense liso
CONMOR	Confite Morocho	DTRGRU	Dente Riograndense rugoso
CONNOR	Cónico Norteño	DULCE	Dulce
CONPUN	Confite Puneño	DULNOR	Dulcillo del noreste
CORDIL	Cordellera	DURANG	Durango-teosinte
CORNBD	Corn belt dent	DZITBA	Dzit-Bacal
COROAM	Coroico Amarillo	EARCAR	Early Caribbean
COROBL	Coloico Blanco	ELOTCO	Elotes conicos
COROIC	Coroico	ELOTOC	Elotes occidentales
COSCOM	Coscomatepec	ENANO	Enano
COSTEN	Costeño	ENANOG	Enano gigante
COTRFT	Coastal tropical flint (also COSTCR)	ENTREL	Interlocked
CRAMAN	Cristalino amarillo anaranjado	ETO	ETO
CRAVPA	Cravo Paulista	FASCIA	Faciado-faciated.
CRAVRG	Cravo Riograndense	FTCUBA	Cuban flint
CRCHAV	Cristalino Chavantí	GALLIN	Gallina
CRCHGR	Cristalino Chileno Grande	GORDO	Gordo
CRCHIH	Cristalino de Chihuahua	GRANAD	Granada
CRCHIL	Cristalino Chileno	GRUESO	Grueso
CRILAR	Cristalino Largo	GUARIB	Guaribero
GUATEM	Guatemala-teosnte	MUSHIT	Mushito
GUIRUA	Guirua	NALTE8	Nal-tel de ocho
HAITWH	Haiti white	NALTEL	Nal-tel
HAITYE	Haiti yellow	NEGALT	Negro de altura (Negro de tierra fria)
HARIN8	Harinoso de ocho	NEGCHI	Negro de Chimaltenango
HARINO	Harinoso	NEGRIT	Negrito
HARTAR	Harinoso Tarapaqueño	NEGRO	Negro
HICKKG	Hickory king	NEGTIC	Negro de tierra caliente
HUACHA	Huachano	NOBOGA	Nobogame-teosinte
HUALCO	Hualtaco colorado	NORCAT	Cateto nortista
HUALTA	Hualtaco	NTAMTA	Nal-tel amarillo tierra alta
HUANCA	Huancavelicano	NTAMTB	Nal-tel amarillo tierra baja
HUANDA	Huandango	NTBLTA	Nal-tel blanco tierra alta
HUARMA	Huarmaca	NTBLTB	Nal-tel blanco tierra baja
HUAYCH	Huaychano	8CORRI	Ocho corridas
HUAYLE	Huayleño	OKE	Oke
HUEHUE	Huehuetenango-teosinte	OLOTIL	Olotillo
HUESIL	Huesillo	OLOTO8	Olotón de ocho
HUEVIT	Huevito	OLOTÓN	Olotón
HUILLC	Huillcaparu	ONAVEN	Onaveño
IGUENO	Igueno	PADENT	Dente paulista
IMBRIC	Imbricado	PAGALA	Pagaradroga
JALA	Jala	PAILÓN	Pailón
JANKAS	Janka sara	PALOME	Palomero
KAJBIA	Kajbia	PARDO	Pardo
KARAPA	Karapampa	PARO	Paro
KCELLO	Kcello Ecuatoriano	PARU	Paru
KCULLI	Kculli	PARY	Pary
KELLU	Kellu	PATIGR	Patillo grande
KEPSIQ	Kepisiqui	PATILL	Patillo
KULLI	Kulli	PEPITI	Pepitilla

LADYFI	Lady finger	PERLA	Perla
LENHA	Lenha	PERLAM	Perla amarillo
LIMENO	Limeno	PERLIL	Perlilla
MAIZON	Maizon	PERLIT	Perlita
MARANO	Maraño	PEROLA	Perola
MARCAM	Marcame	PINTFT	Pinto flint
MARRON	Marron	PIPOCA	Pipoca-Pop corn
MCUBAN	Cuban yellow flint /dent (also CUBANO)	PIRA	Pira
MDULCE	Maize dulce	PIRICI	Piricinco
MEZCLA	Mixture of races	PIRNAR	Pira naranja
MISHCA	Mishica	PISANK	Pisinkalla, Pisincho (also PISINC)
MOCHER	Mochero	TUNICA	Tunicado
MONTAN	Montaña, Colombia/Ecuador	TUSILL	Tusilla morado
MORADO	Morado	TUSON	Tuson or Tuzon
MORBLA	Morocho blanco	TUXNOR	Tuxpeño norteño
MORCAJ	Morocho Cajabambino	TUXPEN	Tuxpeño
MORCAN	Morado Canteno	UCHIMA	Uchima
MOROCH	Morocho	PISCOR	Piscorunto
MOROTI	Moroti	PISINC	Pisinkalla, Pisincho (also PISANK)
MORPRE	Moroti precoce	PISING	Pisingallo
MRULO	Maiz de rulo	PISINK	Pisinkalla, Pisincho (also PISANK)
QUICHE	Quicheno	POJCHI	Pojoso chico, Bolivia
QUICHG	Quicheno grande	POJOSO	Pojoso chico, Ecuador
PURITO	Purito	POLLO	Pollo
PUYA	Puya	POLULO	Polulo
PUYAGR	Puya grande	POPCOR	Pop corn
QUICHL	Quicheño late	PURITO	Purito
QUICHR	Qucheño rojo	UCHUQU	Uchuquilla
RABODE	Rabode zorro	UNCLAS	Unclassified
RACIMO	Racimo de uva	USPOP	U.S. pop corn type
REDDNT	Red dent	VANDEN	Vandeño
REDFLT	Red flint	VENEZO	Venezolano
REVENT	Reventador	WHPOP	White pop corn
RGDENT	Riogrande dent	XMEHEN	Xmehenal
RGWHDT	Riogrande white dent/dente branco	YUCATA	Yucatan
RIENDA	Rienda	YUNGA	Yunga
SABANE	Sabanero	YUNGUE	Yungueño
SALPOR	Salpor	YUNQUI	Yunquillano
SALVAD	Salvadoreño	ZAMOAM	Zamorano amarillo
SANGER	San Geronimo	ZAPCHI	Zapalote chico
SANJER	San Jerónimo (also SANGER)	ZAPGRA	Zapalote grande
SANMAR	San Marceño		
SARCO	Sarco		
SDENPA	Semi dentado paulista		
SDENRG	Semidentado Riograndense		
SDENTA	Semi dentado		
SEMANE	Semanero		
SERRAN	Serrano		
SHAJAT	Shajata		
SHIMA	Shima		
SNJUAN	San Jan		
SPWHDT	Sao Paulo white dent /dente branco paulista		
STCROI	Saint Croix		
SYIVAM	Synthetic ivaí amarello		
TABLI8	Tablilla de ocho		

TABLIL	Tablilla
TABLON	Tabloncillo
TABPER	Tabloncillo perla
TAMAUL	Tamaulipeco
TAMBOP	Tambopata
TAMPIQ	Tampiqueño
TEHUA	Tehua
TEPECI	Tepecintle
TUIMUR	Tuimiru

Field Book Evaluation Data Codes/Definitions for Accessions

It is desirable to standardize the data codes and definitions used in field books for evaluation of accessions. We have summarized below the current data codes and definitions that the CIMMYT maize bank has used. The evaluation data that has been compiled on a CD-ROM (Taba et al. 2003) use the same data codes and definitions as presented here.

CODE	Definition
CL	Homogeneous groups made by Normix after Wards
ENTRY	Unique entry identification in the experiment
ACCID	Accession identifier of CIMMYT Maize genetic resources.
COUNTRY	Coded for the country according to ISO standard
ACCESSION NAME	Collection number of the accession
GT1	Grain Type 1 coded, more frequent
GT2	Grain Type 2 coded, frequent
GT3	Grain Type 3 coded, less frequent
GC1	Grain Color 1 coded, more frequent
GC2	Grain Color 2 coded, frequent
GC3	Grain Color 3 coded, less frequent
RACE 1	Primary race name or local name
PURITY	Purity in scale 5-9, 5-less pure; 9-race type
RACE 2	Secondary race name or local name
ALT.	Altitude(masl) where experiment is conducted
GE	Field germination (%)
VI	Seedling vigor rating: 1-very good; 5 –poor
TI	Number of tillers per plant
AN	Days from planting to anthesis
SI	Days from planting and silking
PH	Plant height (cm) from soil to tassel top
EH	Ear height (cm) from soil to ear node
LAE	Number of leaves above the ear
HC	Husk cover rating: 1-very good; 5-poor
SE	Days from silking to ear leaf senescence
SL	Stalk lodging (%)
RL	Root lodging (%)
YLD	Yield in kilograms per hectare
MO	Grain moisture (%) at harvest
SH	Shelling (%)
PHV	Number of plants harvested in a plot
EP	Ears per plant
EL	Ear length (cm)

ED	Ear diameter (cm)
ER	Ear rot (%) at harvest
EQ	Ear quality: 1-very good; 5-poor
KRN	Kernel row number
AGS	Agronomic performance scale: 1- very good; 5-poor
KL	Kernel length (cm)
KW	Kernel width (cm)
OB	Observation overall with asterisks (* is shown by 1, ** are shown by 11)
SE/SI	Days from silking to ear leaf senescence / days from planting to silking
EH/PH	Ear height from soil to ear node / plant height from soil to tassel top
YLD/MO	Yield in kilograms per hectare / grain moisture (%) at harvest
CAN1	First canonical variable
CAN2	Second canonical variable
CAN3	Third canonical variable
HP	Heterotic group: pattern A or B
KEY	Preliminary CIMMYT Core subset (1) and the others (0)
SEL	Selection index constructed by yield, % ear rot, % standability, and % moisture at harvest

Codes for Grain Types and Grain Colors in Passport Data

Original landrace accessions often have a mix of grain types and colors. In our passport database, information of grain types and colors are coded for each accession with up to three codes in a series, with the first code for more frequent occurrence. In the evaluation trials, the same codes are used for describing grain color and texture of the accession at harvest. In some cases, there are differences in the descriptors used for passport data and the evaluation data due to xenia effect on grain color. Codes for grain types and colors are listed below.

Code	Grain type	Code	Grain color
A	Floury	A	White
B	Morocho	B	Yellow
C	Dent	C	Purple
D	Semi-dent	D	Variegated
E	Semi-flint	E	Brown
F	Flint	F	Orange yellow
G	Popcorn	G	Mottled
H	Sweet	H	White top
I	Opaque	I	Red
J	Tunicate	J	Sun red
K	Waxy	K	Blue
L	White cap	L	Dark blue
M	Others	M	Others

List of the Evaluation Trials Used for Developing Preliminary Breeder Core Subsets in the CIMMYT Maize Collection

Evaluation trials consisted of races from Mexico, Argentina, Brazil, Chile, Paraguay, as well as Central American and Caribbean races. Only the highland races from Mexico were evaluated. Trial entries were searched by primary and secondary race name from passport data in CIMMYT's maize bank database (MZBANK). When the number of accessions was too large to include them in one trial, they were evaluated in a set of trials, with each trial having a unique field book number. Field book number, title of the trial, and trial site are used to access the evaluation data in Excel files. Trial sites were mostly CIMMYT experimental stations, with the exception of a few outside stations. PR indicates the tropical lowland experiment station of Poza Rica, Veracruz (latitude N20: 32 and longitude W97:26, and an altitude of 60 masl). TL indicates the tropical/subtropical mid altitude station, Tlaltizapan, Morelos (latitude N18:41 and longitude W99:08, and altitude 940 masl). BA indicates the highland station of El Batán, CIMMYT headquarters, Mexico (latitude N19:31 and longitude W98:50, and altitude 2240 masl). Cycle A indicates planting in October through December, and cycle B indicates planting in May-July. El Batán station is planted in April-May.

Bank evaluation data files on CD-ROM (Taba et al. 2003) include evaluation data listed by accession number. Some accessions were evaluated many times in these evaluation trials. We included evaluation data available across all trials from the bank database, by accession number. "All trials" in the CD indicates data from across evaluation trials compiled so far for the accessions in the trial. Performance of the accessions in different environments is recorded. All evaluation trials that were summarized on CD-ROM for the preliminary breeder core subsets of CIMMYT's maize collection are listed below.

Mexican races

Races Apachito, Azul, Cristalino de Chihuahua, Elotes Occidentales, Gordo, Maize Dulce, and Lady Finger-northern highland races of Mexico:

Trial 1: Northern highlands races of Mexico.
Field book number: 84.
Trial site: BA1996-2909.

All trials: Performance by races: Apachito, Azul, Cristalino de Chihuahua, Elotes Occidentales, and Gordo in all trials.

Races Arrocillo Amarillo, Arrocillo Blanco, Cacahuacintle, Elotes Cónico, Mushito, and Palomero Toluqueño:

Trial 1: Arrocillo Amarillo, Arrocillo Blanco, Cacahuacintle, Elotes Cónico, Mushito, and Palomero Toluqueño: Central highland races of Mexico.
Field book number: 85.
Trial site: BA1996-2910.

All trials: Performance of Arrocillo Amarillo, Arrocillo Blanco, Cacahuacintle, Elotes Cónico, Mushito, and Palomero Toluqueño in all trials.

Race Bolita:

Trial 1: Primary or secondary race Bolita accessions.
Field book numbers: 143, 146.
Trial sites: TL1995A-1970, BA1995-2909.

All trials: Performance of race Bolita accessions-compilation of available evaluation data at all sites.

Race Celaya:

Trial 1: Primary or secondary race Celaya accessions.
Field book numbers: 111, 115, 116.
Trial sites: BA1991-2971, PR1991B-5970, TL1991B-6970.

Trial 2: Primary or secondary race Celaya accessions introduced in the 1990s.
Field book numbers: 181,182.
Trial sites: TL1999B-6909, BA1999-2909.

All trials: Performance by race Celaya accessions-compilation of available evaluation data at all sites.

Race Chalqueño:

Trial 1: Primary or secondary race Chalqueño accessions.
Field book number: 125, 137.
Trial sites: BA1993-2970, BA1994-2970.

All trials: Performance by race Chalqueño accessions-compilation of available evaluation data at all sites.

Race Cónico:

Trial 1: Primary or secondary race Cónico accessions.
Field book number: 100.
Trial site: BA1990-2970.

Trial 2: Primary or secondary race Cónico accessions.
Field book number: 101.
Trial site: BA1990-2971.

Trial 3: Primary or secondary race Cónico accessions.
Field book number: 102.
Trial site: BA1990-2972.

Trial 4: selected accessions (about 20%) of race Cónico from Trial 1, 2, and 3.
Field book numbers: 112, 113, 114.
Trial sites: BA1991-2970, Montecillo1991-0970, Tecamac1991-0970.

All trials: Performance by race Cónico accessions-compilation of available evaluation data at all sites.

Race Cónico Norteño:

Trial 1: Primary or secondary race Cónico Norteño accessions.
Field book number: 119.
Trial site: BA1992-2970.

Trial 2: Primary or secondary race Cónico Norteño accessions.
Field book number: 120.
Trial site: BA1992-2971.

Trial 3: Selected accessions (about 20%) of Cónico Norteño from Trial 1 and 2.
Field book numbers: 126, 136.
Trial sites: BA1993-2971, BA1994-2971.

All trials: Performance by race Cónico Norteño accessions-compilation of available evaluation data at all sites.

Race Elotes Cónicos:

Trial 1: Primary or secondary race Elotes Cónicos accessions.
Field book number: 193.
Trial site: BA2001-2909.

All trials: Performance by race Elotes Cónicos accessions-compilation of available evaluation data at all sites.

Races Nal-Tel, Zapalote Chico, Zapalote Grande, Dzit-Bacal, and Clavillo:

Trial 1: Primary or secondary race Nal-Tel, Zapalote Chico, Dzit-Bacal, Clavillo, and Zapalote Grande from Mexico.
Field book number: 150.
Trial site: PR1995B-5909.

Trial 2: Primary or secondary race Zapalote Chico, Nal-Tel, Dzit-Bacal, and Clavillo accessions from Costa Rica, Guatemala, Panama, and Mexico (Chiapas-Yucatán-Oaxaca-Campeche).
Field book number: 151.
Trial site: PR1996A-0909.

Trial 3: Primary or secondary race Nal-Tel, Zapalote Chico, Dzit-Bacal, Clavillo accessions from Costa Rica, Guatemala, Panama, and Mexico (Chiapas-Yucatán-Oaxaca-Campeche).
Field book number: 152.
Trial site: PR1996A-0910.

All trials for Nal-Tel: Performance by race Nal-Tel accessions-compilation of available evaluation data at all sites.
All trials for Zapalote Chico: Performance by race Zapalote Chico accessions-compilation of available evaluation data at all sites.
All trials for Zapalote Grande: Performance by race Zapalote Grande accessions-compilation of available evaluation data at all sites.
All trials for Dzit-Bacal: Performance by race Dzit-Bacal accessions-compilation of available evaluation data at all sites.
All trials for Clavillo: Performance by race Clavillo accessions-compilation of available evaluation data at all sites.

Race Olotillo:

Trial 1: Primary or secondary race Olotillo accessions.
Field book numbers: 108, 109.
Trial sites: PR1991A-0971, TL1991A-1971.

All trials: Performance by race Olotillo accessions-compilation of available evaluation data at all sites.

Races Tabloncillo, Reventador, Chapalote, Maize Dulce, Harinoso de Ocho, Tabloncillo Perla, Bofo, and Onaveño:

Trial 1: Primary race or secondary race Tabloncillo, Reventador, Chapalote, Maize Dulce, Harinoso de Ocho, Tabloncillo Perla, Bofo, and Onaveño.
Field book number: 15.
Trial site: TL1989B-6930.

All trials: Performance of races: Tabloncillo, Tabloncillo Perla, Reventador, Chapalote, Maize Dulce, Harinoso de Ocho, Bofo, Onaveño-compilation of available evaluation data at all sites.

Race Tepecintle:

Trial 1: Primary or secondary race Tepecintle accessions.
Field book numbers: 110, 148.
Trial sites: PR1991A-0972, TL1995B-6919.

All trials: Performance of race Tepecintle accessions-compilation of available evaluation data at all sites.

Race Tuxpeño:

Trial 1: Primary or secondary race Tuxpeño accessions grouped by wet ecology of Mexican states where they were collected.
Field book numbers: 13,14.
Trial sites: PR1989A-0970, TL1989B-5970.

Trial 2: Primary race or secondary race Tuxpeño accessions grouped by dry ecology of Mexican states where they were collected.
Field book numbers: 9, 16.
Trial sites: TL1988B-6970, PR1989B-8970.

Trial 3: Primary or secondary race Tuxpeño accessions grouped by mixed ecology (wet and dry) of Mexican states where they were collected.
Field book numbers: 12, 19.
Trial sites: TL1989A-1970, PR1990A-0970.

Trial 4: Primary or secondary race Tuxpeño accessions grouped by intermediate-highland collection sites.
Field book number: 105.
Trial sites: TL1990B-6970.

Trial 5: Accessions (20%) selected from Trial 1, 2, 3, 4.
Field book number: 106, 107.
Trial sites: PR1991A-0970, TL90B-6970.

Trial 6: Primary or secondary race Tuxpeño accessions introduced in the 1990s.
Field book numbers: 180,188, 189.
Trial sites: PR1999B-5909, PR2000B-5909, TL2000B-6909.

All trials: Performance by race Tuxpeño accessions-compilation of available evaluation data at all sites.

Race unclassified in the previous records and race composites:

Trial 1: Part of Mexican accessions that had no race classification available in the passport data.
Field book number: 18.
Trial site: TL1990A-1931.

Trial 2: Composites that were made of the race accessions.
Field book number: 134.
Trial site: TL1994A-1971.

Race Vandeño:

Trial 1: Primary or secondary race Vandeño accessions.
Field book numbers: 20, 147.
Trial sites: PR1990A-0971, TL1995B-6909.

All trials: Performance of race Vandeño accessions-compilation of available evaluation data at all sites.

Caribbean and Central American Lowland Races

Races Coastal Tropical Flint, Cuban Yellow Flint, Chandelle, Early Caribbean, Tusón, and others:

Trial 1: Accessions with race classifications Coastal Tropical Flint or Criollo from The Caribbean, including Caribbean coastal regions of Central America and South America.
Field book: 121,122, 130,132.
Trial sites: PR1992B-5970, TL1992B-6970, PR1994A-0970, TL1994A-1970.

Trial 2: Accessions with race classifications: Argentino, Canilla, Cuarenton Cateto, Cateto Nortista Precoce, Cateto Sulino, Chandelle, Clavillo, Cuban yellow flint, Early Caribbean, Cuban flint, Haiti Yellow, Haiti White, Cateto Nortista, Puya, Salvadoreño, Saint Croix, Tusón, unclassified.
Field book numbers: 123,124, 127,128.
Trial sites: PR1993A-0970, TL1993A-1970, PR93B-5970, TL1993B-6970.

Trial 3: Further evaluation of selected accessions from trial 1 and 2.
Field book number: 141.
Trial site: TL1994B-6970.

Trial 4: New introductions of Caribbean germplasm in the 1990s.
Field book number: 179.
Trial site: PR1999A-0909.

All trials for Coastal Tropical Flint, Canilla, Chandelle, Clavillo, Haiti White, Haiti Yellow, Puya, Saint Croix, Cuban yellow flint, Cuban Flint, Early Caribbean, and Tusón: Performance of these races in all trials sites.

Races Puya, Puya Grande, Clavillo, Costeño, Gúaribero, Común, Chandelle, Huevito, etc.:

Trial 1: Primary or secondary race Puya, Puya Grande, Clavillo, Costeño, and Gúaribero accessions from Centro America, Venezuela, and Colombia.
Field book numbers: 93, 154.
Trial sites: PR1997A-0909, PR96B-5909.

Trial 2: Primary or secondary race Común, Costeño, Chandelle, Huevito, Pailon, Puya, Puya grande, Cuban Yellow (Cubano Amarillo), etc. from Venezuela, Cuba, Colombia, Trinidad, etc.
Field book number: 117, 118.
Trial sites: PR1992A-0970, TL1992A-1970.

All trials: Performance by race Puya, Puya Grande, Costeño, and Gúaribero-compilation of available evaluation data at all sites.

Race Salvadoreño:

Trial 1: Primary or secondary race Salvadoreño accessions.
Field book numbers: 138, 139.
Trial sites: PR1994B-5970, PR1995A-0970.

All trials: Performance by race Salvadoreno-compilation of available evaluation data at all sites.

Races of Argentina, Chile, Paraguay, Uruguay, and Brazil

Race Cateto Sulino:

Trial 1: Primary or secondary race Cateto Sulino from Uruguay.
Field book number: 75.
Trial site: TL1996A-1909.

Trial 2: Primary or secondary race Cateto Sulino from Uruguay.
Field book number: 76.
Trial site: TL1996B-6910.

Trial 3: Primary or secondary race Cateto Sulino from Argentina, Brazil, and Uruguay.
Field book number: 184.
Trial site: TL2000A-1909.

All trials: Performance by race Cateto Sulino-compilation of available evaluation data at all sites.

<u>Race Cristalino Colorado, Cristalino Amarillo Anaranjado, and Cristalino Amarillo from Argentina:</u>

Trial 1: Accessions of Cristalino Colorado, Cristalino Amarillo Anaranjado, and Cristalino Amarillo from Argentina.
Field book number: 200.
Trial site: TL2002A-1909.

<u>Race Dente Paulista:</u>

Trial 1: Primary or secondary race Dente Paulista from Brazil.
Field book number: 160.
Trial site: PR1997B-5909.

Trial 2: Primary or secondary race Dente Paulista from Brazil.
Field book number: 142.
Trial site: PR1998A-0909.

Trial 3. Primary or secondary race Dente Paulista accessions.
Field book number: 178.
Trial site: TL1999A-1909.

All trials: Performance by race Dente Paulista-compilation of available evaluation data at all sites.

<u>Race Dente Riograndense and Dente Riograndense Rugoso and Liso from Brazil:</u>

Trial 1: Primary or secondary race Dente Riograndense Rugoso and Liso accessions.
Field book number: 159.
Trial site: TL1997B-6909.

Trial 2: Primary or secondary race Dente Riograndense of Brazil.
Field book number: 140.
Trial site: TL1998A-1909.

All trials: Performance by race Dente Riograndense and Dente Riograndense Rugoso and Liso-compilation of available evaluation data at all sites.

<u>Race Dentado Blanco, Semi-dentado Riograndense, Cateto Sulino Grosso, etc. From Uruguay:</u>

Trial 1: Accessions of Dentado Blanco, Semi-dentado Riograndense, Cateto Sulino Grosso, etc. from Uruguay.
Field book number: 94.
Trial site: TL1997A-1910.

<u>Race Sape Pytá, Sape Morotí, Tupi Morotí, and Tupi Pytá from Paraguay:</u>

Trial 1: Accessions of Sape Pytá, Sape Morotí, Tupi Morotí, and Tupi Pytá from Paraguay.
Field book number: 196.
Trial site: TL2001B-6909.

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References

Anderson, E. and H.C. Cutler. 1942. Races of *Zea mays*: I. Their recognition and classification. *Ann. Mo. Bot. Gard*. 29: 69-89.

Brieger, F.G., J.T.A. Gurgel, E. Paterniani, A. Blumenschein, and M.R. Alleoni. 1958. Races of maize in Brazil and other eastern South American countries. Pub. 593, NAS-NRC, Washington DC.

Brown, W.L. 1953. Maize of the West Indies. *Trop. Agric*. 30:141-170.

Brown, A.H.D. 1989. Core collections: a practical approach to genetic resources management. *Genome* 31: 818-824.

Brown, A.H.D. 1995. The core collection at the crossroads. In T.Hodgkin, A.H.D. Brown, T.J.L. van Hintum and E.A.V. Morales (eds.), *Core Collections of Plant Genetic Resources*. John Wiley and Sons, Chichester, UK. pp. 3-19.

Brown, A.H.D., and C. Spillane. 1999. Implementing core collections-principles, procedures, progress, problems and promises. In R.C. Johnson and T. Hodgkin (eds.), *Core collections for today and tomorrow*. International Plant Genetic Resources Institute, Rome, Italy. pp. 1-9.

Crossa, J., K. Basford, S.Taba, I. Delacy, and E.Silva. 1995. The three mode analyses of maize using morphological and agronomic attributes measured in multilocational trials. *Crop Sci*. 35: 1483-1491.

Franco, J.E., J. Crossa, J. Díaz, S. Taba, and S.A. Eberhart. 1997. A sequential clustering strategy for classifying gene bank accessions. *Crop Sci*. 37: 1656-1662.

Goodman, M.M., and W.L. Brown. 1988. Races of corn. In G.F. Sprague and J.W. Dudley (eds.), *Corn and corn improvement*. ASA, CSSA, SSSA, Madison, WI. pp.33-79.

Grant, U.J., W.H. Hatheway, D.H. Timothy, C. Cassalett D., and L.M. Roberts. 1963. Races of maize in Venezuela. Pub. 1136. NAS-NRC, Washington DC.

Grobman, A., W. Salhuana, and R. Sevilla, with P.C. Mangelsdorf. 1961. *Races of maize in Peru*. Pub. 915, NAS-NRC, Washington DC.

Hatheway, W.H. 1957. *Races of maize in Cuba*. Pub. 453. NAS-NRC, Washington, DC.

Mahalanobis, P.C. 1930. On tests and measures of group divergences. *Journal and proceedings of the Asiatic Soc. Bengal*. 26: 541-588.

NAS-NRC. 1954. Collections of original strains of corn I. Report of the committee on preservation of indigenous strains of maize. Division of Biology and Agriculture, Agricultural Board, Washington, D.C. USA. pp.1-300.

NAS-NRC. 1955. Collections of original strains of corn II. Report of the committee on preservation of indigenous strains of maize. Division of Biology and Agriculture, Agricultural Board, Washington, D.C. USA. pp. 301-592.

Pardey, P.G., B. Koo, B.D. Wright, M.E.V. Dusen, B.Skovmand, S. Taba. 2001. Costing the conservation of genetic resources: CIMMYT's ex situ maize and wheat collection. *Crop Sci*. 41: 1286-1299.

Paterniani, E. and M.M. Goodman. 1977. Races of maize in Brazil and adjacent areas. CIMMYT, Mexico.

Roberts, L.M., U.J. Grant, R. Ramírez E., W.H. Hatheway, and D.L. Smith, with P.C. Mangelsdorf. 1957. Races of maize in Colombia. Pub. 510, NAS-NRC, Washington, DC.

SAS Institute Inc. 1996. SAS/STAT Software: Changes and enhancements through Release 6.11. Cary, NC.

Taba, S. 1995. Maize Germplasm: Its spread, use, and strategies for conservation. In S. Taba (ed.), *Maize genetic resources*, Maize Program Special Report. Mexico, D.F.:CIMMYT. Pp. 7-58.

Taba, S. 1997. A. Maize. In D. Fuccillo, L. Seras, and P. Stapleton (eds.), *Biodiversity in trust*. Cambridge University Press, Cambridge, UK. Pp.213-226.

Taba, S., F. Aragón, J. Díaz, H. Castro, and J.M. Hernández. 1998a. Local maize cultivars for their conservation and improvement in Oaxaca, Mexico. In P. Ramírez, V., F. Zavala G., N.O. Gomez M., F. Rincón S. y A. Mejia C. (eds.), *Memorias del XVII Congreso de Fitogenetica: Notas cientificas* SOMEFI. Chapingo, Mexico. pp.218.

Taba, S., J. Díaz, J. Franco, and J. Crossa. 1998b. Evaluation of Caribbean maize accessions to develop a core subset. *Crop Sci*. 38:1378-1386.

Taba, S., J. Díaz, M. Rivas, M. Rodríguez, V. Vicarte, and J. Norgaard. 2003. The CIMMYT maize collection: preliminary evaluation of accessions. CD-ROM. CIMMYT, El Batán, Mexico.

Taba, S., and S.A. Eberhart. 1998. The status of Latin American maize germplasm conservation. In *Latin American maize germplasm conservation: Core subset development and regeneration*. Proceedings of a workshop held at CIMMYT, June-1-5, 1998. El Batán, Texcoco, México. pp. 1-5.

Taba, S., F. Pineda, and J. Crossa. 1994. Forming core subsets from Tuxpeño race complex. In S. Taba(ed.), *The CIMMYT maize germplasm bank: genetic resource preservation, regeneration, maintenance, and use*. CIMMYT Maize Program Special Report, Mexico, D.F.:CIMMYT. pp. 60-81.

Timothy, D.H., B. Peña V., and R. Ramírez E., with W.L. Brown and E. Anderson. 1961. Races of maize in Chile. Pub. 847. NAS-NRC, Washington, DC.

Wellhausen, E.J., L.M. Roberts, and E. Hernández X., with P.C.Mangelsdorf. 1952.

Wellhausen, E.J., A. Fuentes O., A.H. Corzo, with P.C. Mangelsdorf. 1957. *Races of maize in Central America*. Pub. 511. NAS-NRC, Washington D.C.

Wishart, D. 1987. CLUSTAN User Manual. 3rd Ed. Program Library Unit Univ. Edinburgh, Edinburgh.

In situ Conservation and Use of Local Maize Races in Oaxaca, Mexico: A Participatory and Decentralized Approach

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Abstract

Local maize races in the state of Oaxaca were collected and evaluated to enhance the livelihoods of Oaxacan farmers. Initially, intra-racial diversity of the races of Bolita, Zapalote Chico, and Olotón and related races was studied to identify the best accessions for in situ conservation. Later, the accessions chosen using farmers' criteria were improved, and seed was increased to facilitate on-farm production and maintenance by the collaborating farmers. Ideally, information about local maize diversity in all regions of the state of Oaxaca will be provided to farmers and local breeders, and the best germplasm accessions will be improved, maintained, and utilized by them. Such an approach could contribute to increases in maize production in the area.

Key words: In situ conservation, maize races, Bolita, Zapalote Chico, Olotón, Comiteco, local seed bank.

Introduction

Maize, beans, and squash are major crops in the state of Oaxaca, Mexico, providing about 75% of daily calorie intake. Traditional farmers grow maize landraces on about 90% of the total area planted with maize. Maize is planted from sea level to 2,800 masl in different climatic and edaphic conditions, and thirty races of maize have been identified in Oaxaca (Wellhausen et al. 1952; Sánchez et al. 2000; Ortega 2003). Maize is cultivated in association with beans, squash, chili, fig, sesame, peanut, and other crops and is also used for preparing a range of beverages and foods including tamales, tortillas, totopos, tlayudas, and elotes. Farmers have created and conserved genetic diversity in Oaxacan landraces for culinary traits, maturity, and adaptation. Per capita maize consumption is estimated to be 200 kg per year, and current production levels of 601,083 t (SAGARPA 2002) do not meet the demand for Oaxaca's population of 3.4 million (INEGI 2002) (Table 1, Figure 1). To meet the state demand, an additional 150,000 t of maize is needed. To increase maize production, farmers need better seed and agronomic practices. Breeders need to exploit genetic variation for traits of interest in the landraces grown by farmers and should also improve them for valued traits such as yield and culinary characteristics, so that there are more incentives to conserve these landraces on-farm. Table 2 shows the use of landraces in the different maize growing regions in the state of Oaxaca. About 80% of maize production area is planted with the adapted landraces in the different regions (Table 3, Figure 1). Average grain yield in the state is about 1.4 t/ha. However, the average yield in the communities is estimated to be 2.2 t/ha, taking only the harvested areas into account. Rainfed maize production area covers about 550,000 ha, of which 400,000 ha was harvested for grain production. Maize production in irrigated areas was about 50,000 ha in 2002. Fertilizer is used on about 20% of the land planted to maize. Drought, insect damage on plant roots and stored grains, and soil fertility are the most limiting factors for maize production in the state. Acid soils persist in the highlands where Olotón, Serrano Mixe, and Comiteco races are adapted.

Table 1. Maize grain production statistics in the different regions of the state of Oaxaca, Mexico.

Maize region	Growing cycle	Area planted (ha)			Grain production (t)			Estimated monetary values (x1000 peso MX)		
		Total	Irrigated	Rainfed	Total	Irrigated	Rainfed	Total	Irrigated	Rainfed
Mixteca	O-I	5,586	5,586	0	16,758	16,758	0	33,516	33,516	0
	P-V	104,276	5,721	98,555	149,113	20,197	128,916	298,226	40,394	257,832
Central Valley	O-I	8,100	8,100	0	23,490	23,490	0	65,772	65,772	0
	P-V	134,690	8,500	126,190	135,613	24,650	110,963	339,033	61,625	277,408
Coast	O-I	7,000	4,000	3,000	21,500	14,000	7,500	43,000	28,000	15,000
	P-V	83,492	0	83,492	97,797	0	97,797	205,374	0	205,374
Istmo	O-I	27,914	9,301	18,613	47,082	15,742	31,340	94,164	31,484	62,680
	P-V	96,363	6,535	89,828	109,183	11,082	98,101	240,202	24,380	215,822
Sierra Juárez	O-I	2,672	390	2,282	3,637	974	2,663	10,911	2,922	7,989
	P-V	18,605	600	18,005	19,851	1,500	18,351	43,822	3,450	40,372
Cañada	O-I	4,990	695	4,255	9,467	2,446	7,021	18,934	4,892	14,042
	P-V	31,725	485	31,240	39,665	1,552	38,113	91,230	3,570	87,660
Tuxtepec	O-I	25,305	0	25,305	56,217	0	56,217	84,326	0	84,326
	P-V	44,779	0	44,779	75,524	0	75,524	113,286	0	113,286

Note: O-I: fall-winter season planting, P-V: spring-summer season planting.
Source: INEGI 2002. Anuario Estadístico. Oaxaca. Tomo II

Table 2. Forage maize production statistics in the different regions of the state of Oaxaca, Mexico.

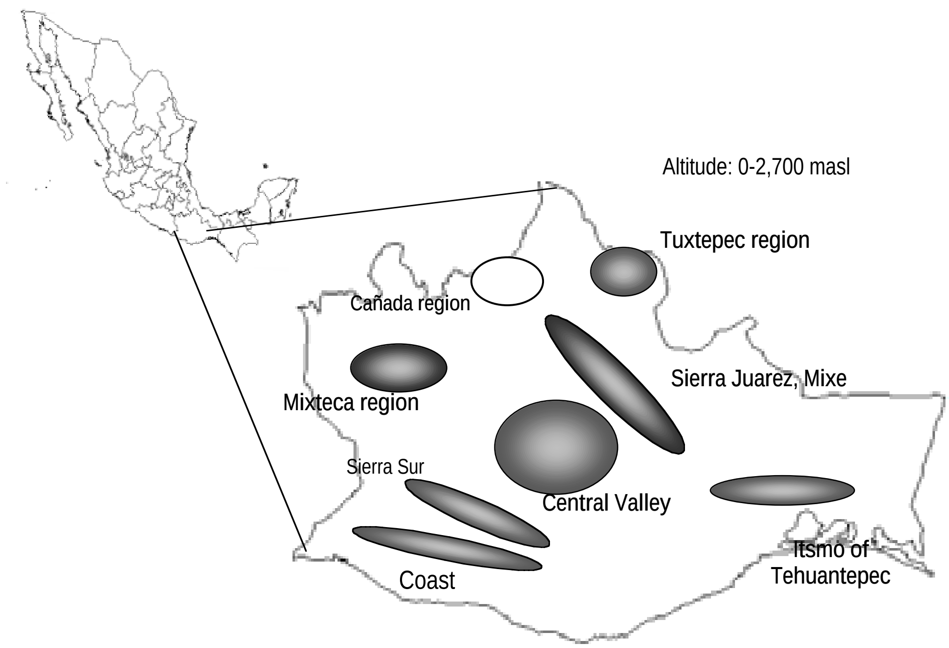
Maize region	Cycle	Are planted (ha)			Forage production (t)			Estimated monetary values (x 1000 pesos MX)		
		Total	Irrigated	Rainfed	Total	Irrigated	Rainfed	Total	Irrigated	Rainfed
Mixteca	O-I	.	.	.	.	.	.	.	.	.
	P-V	40	10	30	1,500	450	1.050	2,025	450	1,575
Central Valley	O-I	463	463	0	16,170	16,170	0	12,936	12,936	0
	P-V	661	215	446	20,080	9,030	11,050	16,466	7,405	9,061
Coast	O-I	.	.	.	.	.	.	.	.	.
	P-V	.	.	.	.	.	.	.	.	.
Istmo	O-I	.	.	.	.	.	.	.	.	.
	P-V	.	.	.	.	.	.	.	.	.
Sierra Juárez	O-I	.	.	.	.	.	.	.	.	.
	P-V	.	.	.	.	.	.	.	.	.
Cañada	O-I	.	.	.	.	.	.	.	.	.
	P-V	.	.	.	.	.	.	.	.	.
Tuxtepec	O-I	.	.	.	.	.	.	.	.	.
	P-V	.	.	.	.	.	.	.	.	.

Note: O-I: fall-winter cycle and P-V: spring-summer cycle.
Source: INEGI 2002. Anuario Estadístico. Oaxaca. Tomo II

Table 3. Cultivated landraces and the estimated production area in the different regions of the state of Oaxaca, Mexico.

Maize regions	Maize landraces grown	Estimated production area (ha) of the landraces
Mixteca	Chalqueño, Cónico	104,000
Central Valley	Bolita, Tepecintle, Pepitilla, Tabloncillo	120,000
Coast	Tuxpeño, Olotillo, Conejito, Tepecintle	80,000
Istmo de Tehauntepec	Zapalote chico, Zapalote Grande, Tuxpeño	100,000
Sierra Juárez –Northern High lands	Olotón, Cónico, Chalqueño, Bolita, Tuxpeño, Comiteco, Serrano Mixe	17,000
Cañada-Southern highlands	Comiteco, Olotón, Tepecintle, Chalqueño	31,000
Tuxtepec-Northern border to the state of Veracruz	Tuxpeño, Tepecintle, Nal-tel, Olotillo	30,000

Figure 1. In situ conservation sites in the state of Oaxaca, Mexico.



In the in situ maize conservation projects described in this paper, three main steps were taken to encourage on-farm acceptance and maintenance of traditional diversity by farmers:

- intra-racial diversity analyzed;
- improvement of the accessions of farmers' maize seed representing that diversity;
- further improvement of these accessions by recombination with desirable traits from elite germplasm.

During each step, farmers were involved in a participatory consultation to identify the germplasm reflecting the desired levels of diversity to be maintained on-farm. This participatory selection and improvement scheme has been implemented for Bolita, Zapalote Chico, Tuxpeño, Olotillo, Tepecintle, Olotón, and related races in Oaxaca. A concerted effort by the non-profit and public sector is needed to support the realization of an effective in situ conservation program for optimal use of the landrace varieties that farmers have cultivated for so many thousands of years.

Race Bolita

Bolita is a well-known maize race in the Central Valley of Oaxaca, used particularly for making a large, thin tortilla called a *tlayuda*. In 1997, 152 farmers' varieties were collected in 15 Central Valley communities. They were evaluated in on-farm trials together with 17 Bolita accessions collected previously in the Central Valley. Due to drought, data were only obtained from 5 of the 15 on-farm trials. Plant and ear traits were measured in replicated trials and included plant height, ear height, days to male and female flowering, ear diameter, kernel width, kernel length, kernel row number, ear length, seed moisture level (%), shelling (%), grain yield, root and stalk lodging (%), and ear quality. Using the adjusted means of 11 traits (except yield, root and stalk lodging, and ear quality), a multivariate analysis was performed to cluster similar accessions into homogeneous groups. The analysis was done with CLUSTAN (Wishart 1987) software, employing the sequential strategy proposed by Franco et al. (1997) (Taba et al. 1998). Accessions were further classified using continuous and categorical variables as described by Franco et al. (1998). The cluster analysis yielded five non-overlapping clusters (a, b, c, d, e) of accessions, which showed the extent of phenotypic variation within the race. To show the patterns of phenotypic diversity within the clusters, canonical discriminant analysis using PROC CAN DISC (SAS 1996) was performed using the adjusted means of the 11 traits used for the multivariate cluster analysis (Franco et al. 1998). Can 1 and Can 2 explained 51% and 40% of the variation, respectively (Figure 2). The best accessions in each cluster (i.e., about 20%, with desired agronomic levels of yield, grain quality, and standability) were chosen to represent the cluster. Table 4 lists the 38 accessions selected to form a core subset of accessions of race Bolita, with the corresponding agronomic data from the on-farm trials. These accessions represent the existing intra-racial genetic diversity of the Bolita race complex.

These accessions were evaluated again in 1998A planting cycle at two locations in the Valley. The best 16 accessions were planted at 4 locations in the summer season of 1998B planting cycle. At the same time, seed of all 38 accessions was increased at CIMMYT and the INIFAP experimental station in the Central Valley of Oaxaca, through plant-to-plant crosses and by selecting ears typical of each accession. Some accessions went through two to three generations of seed increase and selection by full-sib families. These seed lots of selected full-sib ears constituted the foundation of the ongoing half-sib seed increase nursery in the Central Valley. In 1998B and 1999B planting cycles, 4.3 t of seed of the 8 improved accessions were provided to farmers at the same price as grain on the local market. Several more accessions were later added to the selection and seed increase plots. Currently 10 accessions (original farmer varieties; white, yellow, blue, and red) have gone through many cycles of selection, and the improved seed has been made available to farmers.

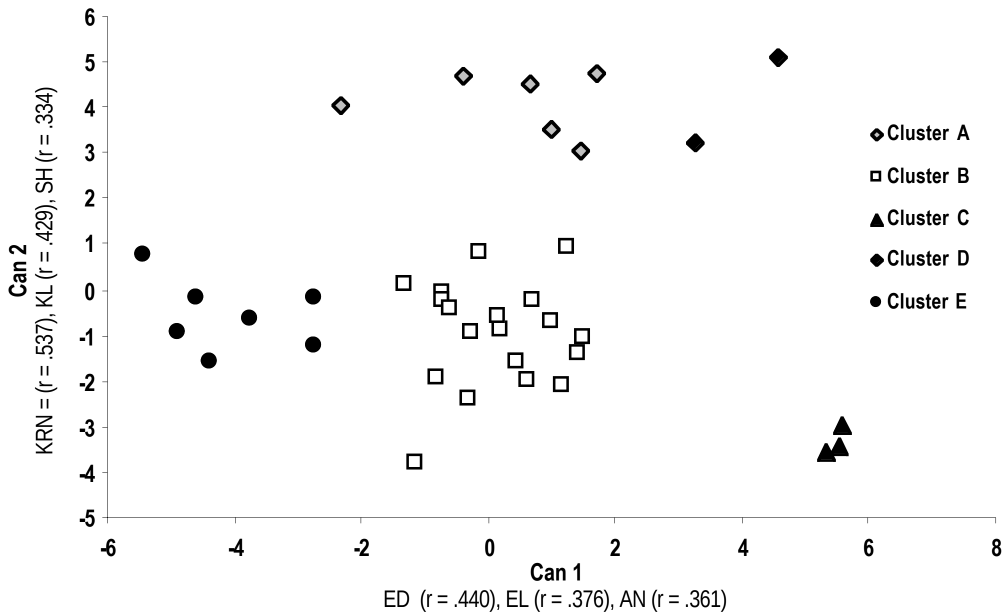
Farmers and local breeders evaluated the accessions at three stages in the on-farm trials: 1997, 1998A, and 1998B (Bellon et al. 2003; Taba 1998; Taba et al. 1998). Demonstrations of the improved local populations were planted in various locations where farmers could observe their agronomic performance. More than 6 t of seed was sold to farmers from 30 different communities in the Central Valley. These landrace populations are maintained in INIFAP's seed bank at the Central Valley experimental station, and they continue to be improved each year.

Table 4. Mean agronomic performance of 38 accessions in the Central Valley of Oaxaca in 1998A cycle, representing intra-racial diversity of Bolita for in situ conservation.

Cluster	Entry	ID Num	Pedigree	Race1	Race2	ALT masl	YLD Mg/ha	GE %	PP	AN	SI	PH cm	EH cm	LD %	EL cm	ED cm	ER %	KRN	KL cm	KW cm	MO %	SH %	SEL %
A	145	20308	OAXACA 145	BOLITA	PEPITI	1310	7.7	62	35	76	79	242	128	15	17	5.4	8	13	1.4	1.0	30	81	87
A	148	20311	OAXACA 148	BOLITA	.	1310	5.9	66	39	73	76	240	128	9	16	5.2	3	12	1.4	1.0	27	81	85
A	170	21200	V-233	BOLITA	.		6.6	73	40	74	75	227	125	11	18	5.3	6	12	1.3	1.0	29	79	82
A	149	20312	OAXACA 149	BOLITA	.	1310	5.3	60	32	71	73	233	113	11	15	5.1	6	12	1.3	1.0	26	85	74
A	23	20186	OAXACA 23	BOLITA	.	1700	5.8	71	40	77	78	241	138	23	16	5.3	5	11	1.3	1.0	26	80	70
A	50	20213	OAXACA 50	BOLITA	.	1620	5.7	68	37	77	79	249	151	21	16	5.4	6	13	1.3	1.0	28	79	64
B	88	20251	OAXACA 88	BOLITA	.	1580	5.7	64	35	70	72	230	113	7	16	5.3	7	9	1.2	1.2	21	80	100
B	42	20205	OAXACA 42	BOLITA	.	1530	6.0	66	39	70	71	235	118	4	15	5.5	10	11	1.2	1.2	22	77	99
B	118	20281	OAXACA 118	BOLITA	.	1447	6.0	68	39	72	74	254	131	7	16	5.1	3	10	1.2	1.1	26	76	91
B	128	20291	OAXACA 128	BOLITA	.	1500	4.8	67	37	69	71	222	106	7	17	5.0	7	8	1.2	1.3	20	77	91
B	129	20292	OAXACA 129	BOLITA	TABLON	1500	5.3	70	40	70	73	248	118	8	17	5.0	3	9	1.2	1.2	24	76	88
B	112	20275	OAXACA 112	BOLITA	.	1580	6.2	69	39	73	75	236	127	10	16	4.9	6	10	1.2	1.1	27	80	86
B	43	20206	OAXACA 43	BOLITA	.	1530	6.2	70	40	74	76	244	130	23	14	5.6	4	11	1.2	1.2	24	78	84
B	30	20193	**OAXACA 30**	BOLITA	.	1710	6.0	62	36	74	76	237	133	16	17	5.1	7	10	1.2	1.1	25	77	82
B	135	20298	OAXACA 135	BOLITA	.	1500	5.6	62	39	72	74	235	121	13	16	5.0	5	10	1.2	1.1	25	80	81
B	40	20203	OAXACA 40	BOLITA	.	1500	5.5	70	38	70	72	230	112	13	16	5.3	5	10	1.2	1.2	25	79	79
B	39	20202	OAXACA 39	BOLITA	.	1500	6.2	62	35	73	75	226	114	23	17	5.5	8	11	1.3	1.1	24	69	78
B	95	20258	OAXACA 95	BOLITA	.	1600	5.2	75	41	73	76	237	119	6	15	5.1	9	10	1.2	1.2	26	68	76
B	126	20289	OAXACA 126	BOLITA	.	1447	6.6	59	36	72	75	236	114	31	17	5.4	8	11	1.3	1.1	24	74	75
B	130	20293	OAXACA 130	BOLITA	.	1500	5.3	70	39	73	75	237	127	9	16	5.0	3	10	1.3	1.2	28	78	75
B	91	20254	OAXACA 91	BOLITA	TABPER	1580	4.8	64	36	72	74	241	122	5	15	5.1	6	10	1.3	1.2	27	76	72
B	134	20297	OAXACA 134	BOLITA	TABPER	1500	4.1	66	37	71	73	239	120	8	14	5.2	6	10	1.2	1.1	24	73	68
B	125	20288	OAXACA 125	BOLITA	.	1447	5.3	70	41	73	75	245	128	14	17	5.3	5	12	1.2	1.1	28	75	66
B	83	20246	OAXACA 83	BOLITA	.	1700	5.1	67	43	74	76	260	137	22	15	5.3	4	12	1.2	1.0	25	77	65
B	138	20301	OAXACA 138	BOLITA	.	1740	5.4	71	38	74	76	245	125	29	16	5.1	4	11	1.1	1.0	27	76	56
B	113	20276	OAXACA 113	BOLITA	PEPITI	1580	4.4	57	31	73	75	206	117	17	16	5.1	7	10	1.3	1.2	26	78	56
C	121	20284	OAXACA 121	BOLITA	.	1447	6.3	71	40	74	75	261	138	12	18	5.5	7	10	1.2	1.3	24	69	95
C	123	20286	OAXACA 123	BOLITA	TABLON	1447	5.9	63	36	74	76	236	113	12	18	5.5	12	10	1.3	1.2	29	69	66
C	41	20204	OAXACA 41	BOLITA	TABLON	1520	5.1	60	34	77	79	243	133	34	17	5.5	5	10	1.2	1.1	29	67	39
D	152	20315	OAXACA 152	TUXPEN	BOLITA	1310	7.6	64	35	86	87	264	157	15	19	5.3	6	14	1.3	0.9	31	74	86
D	45	20208	OAXACA 45	BOLITA	.	1620	6.3	68	38	76	79	261	150	24	18	5.5	10	13	1.2	1.0	28	75	67
E	49	20212	OAXACA 49	BOLITA	.	1620	5.7	60	38	73	74	206	106	6	16	4.7	3	10	1.2	1.2	25	78	92
E	109	20272	OAXACA 109	BOLITA	.	1570	5.5	72	43	68	71	210	103	14	15	5.0	4	11	1.2	1.0	23	79	87
E	131	20294	OAXACA 131	BOLITA	.	1500	5.1	71	39	69	72	207	92	6	15	4.8	5	10	1.1	1.1	24	80	86
E	133	20296	OAXACA 133	BOLITA	PEPITI	1500	5.9	71	41	70	73	230	124	9	16	4.8	4	10	1.2	1.1	26	78	85
E	119	20282	OAXACA 119	BOLITA	.	1447	5.1	64	36	70	71	229	119	11	15	4.8	3	10	1.2	1.1	26	78	74
E	166	20018	OAXACA 435	BOLITA	.	N.A.	4.5	61	34	70	72	224	113	17	15	4.8	3	11	1.1	1.0	23	78	71
E	132	20295	OAXACA 132	BOLITA	.	1500	5.5	69	40	70	73	234	108	21	14	5.0	8	11	1.1	1.0	26	77	66
			MEANS				**5.7**	**66**	**38**	**73**	**75**	**236**	**123**	**14**	**16**	**5.2**	**6**	**11**	**1.2**	**1.1**	**26**	**77**	
			LSD 5%				**2.0**	**18**	**10**	**3**	**2**	**36**	**26**	**25**	**3**	**0.6**	**8**	**2**	**0.2**	**0.2**	**7**	**5**	
			C.V.				**18.0**	**13**	**13**	**2**	**2**	**8**	**11**	**88**	**9**	**5.9**	**72**	**10**	**8.6**	**8.2**	**14**	**3**	

ALT = Altitude; YLD = Yield; GE = Germination; PP = Number of plants; AN = Anthesis (days to male flowering)
SI = Silking (days to female flowering); PH = Plant height; EH = Ear height; LD = Lodging; EL = Ear length
ED = Ear diameter; ER = Ear rot; KRN = Kernel row number; KL = Kernel; KW = Kernel width
MO = Moisture; SH = Shelling; SEL = Selection index [SEL = YLD x (1 - ER/100)/7188 x 100 + (100-LD) - 3.2 x MO]
N.A. = Not available

Figure 2. Phenotypic diversity of 38 accessions of race Bolita from 5 non- overlapping clusters, evaluated at Huitzo and Valdeflores in the Central Valley of Oaxaca, 1998A planting cycle.



Race Zapalote Chico

This type of maize is used for making a special tortilla called *totopos*. In 1999 in Itsmo de Tehuantepec, Oaxaca, Mexico, 69 Zapalote Chico landrace accessions were collected from the households of farmers in 21 villages. At four locations in 2000, these accessions were evaluated along with 12 accessions of this race that were previously collected in the region and drawn from the CIMMYT and INIFAP maize banks. One location was in situ (Sta. Gertrudis Miramar, Tehuauntepec, 50 masl). The other three locations included Tlatizapan (940 masl) and Tepalcingo (1,200 masl) in the state of Morelos, and Iguala (731 masl) in the state of Guerrero. Agro-morphological traits of the accessions were measured, and a cluster analysis was performed on 11 plant and ear traits to form a core subset representative of intra-racial diversity (Franco et al. 1998). Table 5 lists the 18 best accessions for in situ conservation of Zapalote Chico identified in the evaluation trials in 2000 (Taba et al. 2000). Figure 3 shows the patterns of phenotypic diversity of 81 accessions revealed through the canonical discriminant analysis described above. Can 1 and Can 2 explained 85% and 8% of the total variation among the clusters, respectively. These core accessions were evaluated again in Tehuantepec in 2002. The seed of these accessions was simultaneously increased at CIMMYT's Tlaltizapan experimental station.

The accessions were crossed with CIMMYT maize pools 15 and 16 to increase their yield potential. The progeny of these crosses were backcrossed to the same accessions, and BC_1 populations were sib-mated at CIMMYT's Agua Fria experimental station in 2003. The selected and recombined progenies of the breeding crosses will undergo participatory variety selection by farmers in Tehuautepec. We tried to introgress the yield potential of the early, tropical pools into the accessions because they showed a narrow range of variation in yield. At the same time, we sought to maintain the desirable traits of the race, such as its early maturity, grain quality for making totopos, and good husk cover. Seed of the best accessions will be increased by chain crosses among the plants in each accession, and the progenies will be evaluated together with the enhanced BC_1 populations. We have analyzed intra-racial diversity, formed enhanced populations (BC_1) with allele introgression for desired traits (e.g., grain yield, ear rot resistance, and lodging resistance), and further improved them for recombination and selection for on-farm conservation. These enhanced populations will soon be tested on-farm.

Figure 3. Six non-overlapping clusters to show phenotypic diversity among 81 accessions of Zapalote Chico evaluated at Tlaltizapan, Itsmo de Tehuantepec, Tepalcingo, and Iguala in 2000A planting cycle.

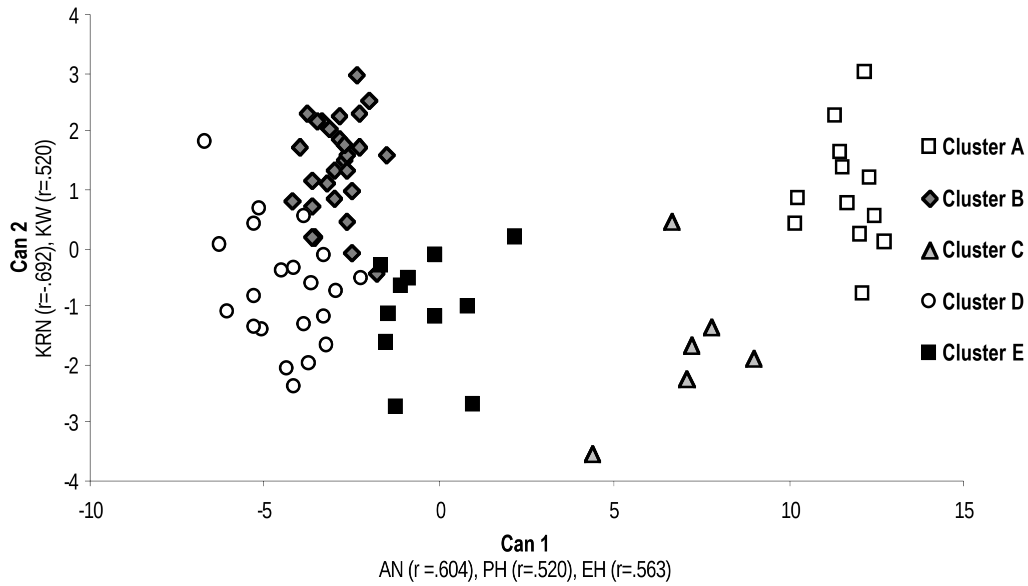


Table 5. Means of agronomic traits of the best 18 accessions of Zapalote Chico at Tlaltizapan and Tepalcingo in the state of Morelos, Iguala in the state of Guererro, and Itsmo de Tehuantepec, Oaxaca, Mexico in 2000.

Cluster	Entry	Id Num	Pedigree	Race1	Race 2	ALT	YLD	GE	PP	AN	SI	PH	EH	LD	EL	ER	ED	KRN	KL	KW	MO	SH	SEL
						masl	kg/ha	%				cm	cm	%	cm	%	cm		cm	cm	%	%	
a*	9	23544	OAXA 848	OLOTIL8		325	4489	78	38	84	93	201	118	17	15	8	4.3	12	1.22	0.89	22	90	85
a*	2	23537	OAXA 841	TEPECI6		900	2631	86	36	93	75	211	130	12	15	15	4.5	13	1.14	0.97	26	80	25
b*	60	23595	OAXA 899	ZAPCHI		100	3166	90	43	72	67	148	79	21	12	21	4.4	10	1.05	1.00	11	87	92
b*	27	23562	OAXA 866	ZAPCHI		100	3035	86	38	69	70	139	70	21	12	18	4.4	10	1.17	1.03	11	89	89
b*	34	23569	OAXA 873	ZAPCHI		100	2801	90	35	71	67	146	76	16	12	18	4.3	11	1.08	0.95	12	88	86
b*	57	23592	OAXA 896	ZAPCHI		100	3005	89	39	71	68	134	68	19	11	20	4.4	10	1.12	0.99	12	89	85
b*	46	23581	OAXA 885	ZAPCHI		100	2851	89	41	73	68	152	75	26	12	12	4.3	11	1.13	0.98	12	86	82
b*	50	23585	OAXA 889	ZAPCHI		100	3049	90	38	69	65	138	72	24	12	15	4.4	10	1.22	1.00	14	89	79
b*	59	23594	OAXA 898	ZAPCHI	BOLITA	100	2961	87	37	73	68	153	80	26	12	22	4.5	10	1.18	1.11	12	85	77
c*	29	23564	OAXA 868	TEPECI	ZAPGRA	100	4280	75	37	85	78	181	100	19	14	16	4.9	13	1.13	0.94	23	81	64
d*	67	23602	OAXA 906	ZAPCHI		100	2798	90	42	71	66	143	69	15	11	9	4.4	11	1.08	0.92	12	86	91
d*	49	23584	OAXA 888	ZAPCHI		100	2354	88	36	68	63	135	64	10	10	24	4.1	10	1.17	0.95	11	91	84
d*	24	23559	OAXA 863	ZAPCHI		100	2473	80	41	70	65	130	64	21	11	15	4.5	12	1.10	0.94	10	87	84
d*	68	23603	OAXA 907	ZAPCHI	PEPITI	800	2491	88	33	65	62	144	72	22	10	26	4.3	10	1.25	0.95	11	91	74
e*	66	23601	OAXA 905	ZAPCHI		100	2776	86	38	75	70	155	77	14	12	12	4.3	12	1.05	0.91	12	85	90
e*	61	23596	OAXA 900	ZAPCHI		100	2915	92	42	76	73	150	82	20	11	16	4.2	11	1.03	0.89	12	88	84
e*	17	23552	OAXA 856	ZAPGRA	OLOTIL	800	3390	94	40	81	76	181	93	17	13	16	4.2	11	1.18	0.88	19	88	66
f*	30	23565	OAXA 869	ZAPCHI		100	2449	85	36	74	68	142	68	13	10	20	4.8	14	1.20	0.76	12	89	81
			Mean				**2995**	**87**	**33**	**74**	**70**	**155**	**81**	**8**	**12**	**17**	**4**	**11**	**1.14**	**0.95**	**14**	**87**	**79**
			LSD5%				**792**			**5**		**17**	**13**	**10**	**2**	**13**	**0.3**	**1**	**0.12**	**0.08**	**5**	**4**	
			C.V.				**15**			**3**		**5**	**8**	**54**	**7**	**36**	**3.4**	**5**	**5.45**	**4.44**	**16**	**2**	

ALT = Altitude; YLD = Yield; GE = Germination; PP = Number of plants; AN = Anthesis (days to male flowering)
SI = Silking (days to female flowering); PH = Plant height; EH = Ear height; LD = Lodging; EL = Ear length
ED = Ear diameter; ER = Ear rot; KRN = Kernel row number; KL = Kernel; KW = Kernel width
MO = Moisture; SH = Shelling; SEL = Selection index [SEL = YLD x (1 - ER/100)/4134 x 100 + (100-LD) - 4.452 x MO]

Race Olotón and Other Races

These races are very late maturing, have white and yellow grain, and are adapted to high elevations. In 1999, 238 samples were collected from the Mazateca, Cuicateca, and Mixe areas of the northern highlands of Oaxaca, Mexico, at elevations of 1,700 - 2,500 masl. That same year, all accessions were evaluated at three on-farm sites and at CIMMYT's El Batán experimental station. At El Batán, the plant height of some accessions was 4.5 m and ear height was 3.0 m. Plants flowered as late as 140 days, apparently showing a photoperiod response. Even at the on-farm sites, most of the accessions were very late and tall. Agro-morphological traits were measured, and the cluster analysis was performed as described in Franco et al. (1998). We found three major dominant racial groups among the clusters: Olotón, Comiteco, and Nal-Tel (Quiche type in Guatemala) (Wellhausen et al. 1957). Twenty accessions were chosen to represent the racial complexes that included the race Olotón, Comiteco, Tepecintle, Nal-Tel, Serrano de Oaxaca, and Bolita. The accessions are adapted to acidic soils and to cool, wet climatic conditions. Of these, four yellow and six white accessions were crossed with CIMMYT highland lines in 2000 to reduce plant and ear height. Table 6 lists the best representative accessions for in situ conservation that represent the phenotypic diversity among the race complexes grown in the northern provinces of Oaxaca (Taba and Díaz 1999; Aragón et al. 2000). Figure 4 shows the patterns of variation among the accessions evaluated in the three on-farm trials in 1999. Clusters a, b, c, d, and e were formed by the regional accessions and cluster f was formed by the reference checks of CIMMYT improved varieties. Can 1 and Can 2 explained 63% and 26% of the total variation between clusters, respectively.

Genetic variation in the race Olotón for plant height, maturity, and ear rot resistance was beyond the normal range that can be managed effectively for further improvement. As noted, these accessions were crossed with CIMMYT highland lines to reduce plant and ear height and maturity. Some were crossed twice with different lines of the same heterotic group. The breeding crosses had 75% or 50% CIMMYT improved germplasm (CML244, CML 349, CML245, yellow development population, population 87 C5, B.T.V.C.M.BA92, A.T.R.L.TL91A) in their racial backgrounds. They were evaluated on-farm with farmers in Mixteca, in 2002. The selected accessions were planted at El Batán in 2003 for full-sib family selection and recombination. Farmers selected the best ones (based on seed and ear types) from on-farm trials. The enhanced progenies that are selected and recombined from the breeding crosses will be evaluated on-farm in 2005. The diversity of these landraces will be conserved on-farm as farmers grow them in their cropping system, in combination with their varieties.

Other Races

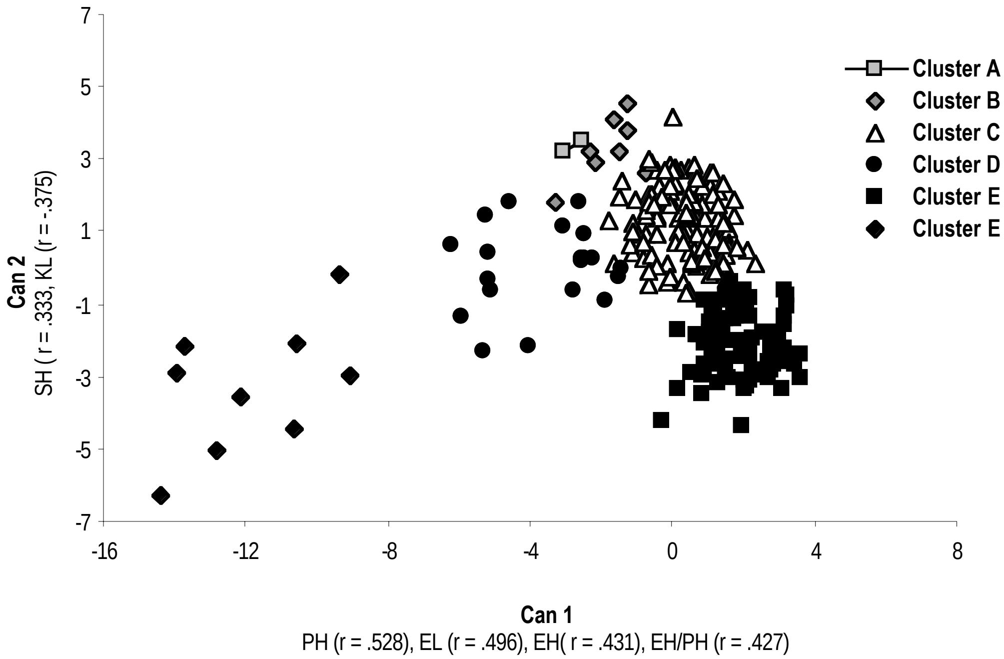
In the southern lowlands and highlands of the state of Oaxaca, other maize races are grown by farmers. These races have been collected and evaluated since 2002 in the same way as the races in the Central Valley and the northern highlands. Farmers in southern Oaxaca use the *milpa* farming system in which maize, beans, and squash are grown in the same field. Their maize races include Olotón, Cónico, Conejo, Tuxpeño, Olotillo, and Comiteco. A total of 246 samples were collected and evaluated in 3 locations. Of these, 25 accessions are being improved for in situ conservation in collaboration with farmers. Tortilla and grain quality traits are being investigated in collaboration with the Centro de Investigación y Estudios Avanzados (CINVESTAV), Querétaro, Mexico.

Table 6. Core accessions representing landrace diversity in the northern highlands of Oaxaca, Mexico, in 1999.

Cluster	Entry	PEDIGREE	Race 1	Race 2	ALT Masl	YLD kg/ha	GE %	PP	AN	SI	PH cm	EH cm	LD %	EL cm	ED cm	ER %	KRN	KL cm	KW cm	MO %	SH %	SEL %
a*	26	41 AMARILLO	NTAMTA		2100	3415	44	37	105	111	258	146	25	16	5	41	14	1.1	0.9	25	80	64
b*	27	42 BLANCO	OLOTÓN	NTBLTA	2100	3773	44	40	110	117	280	161	29	18	5	24	13	1.0	1.0	27	78	82
b*	28	46 AMARILLO	OLOTÓN		2100	3728	46	41	103	109	259	149	28	11	6	33	20	1.2	0.9	26	80	75
c*	113	163 PINTO	OLOTÓN		1860	3691	42	39	105	113	252	132	19	18	5	18	12	1.1	1.0	28	78	95
c*	111	158 BLANCO	OLOTÓN		1860	3703	41	36	106	114	248	141	22	17	5	27	12	1.1	1.0	26	79	85
c*	109	156 AMARILLO	OLOTÓN	QUICHE	1860	4092	38	32	114	119	294	172	22	20	5	24	12	1.1	1.1	31	79	85
c*	183	258 AMARILLO	OLOTÓN		2100	2894	40	36	97	106	229	110	15	15	5	33	10	1.0	1.2	22	80	84
c*	101	146 AMARILLO	OLOTÓN		1860	3821	42	36	118	126	291	177	25	19	5	26	12	1.1	1.0	27	78	84
c*	123	174 BLANCO	OLOTÓN		1950	4122	42	35	107	112	267	145	24	18	5	35	13	1.2	1.0	27	80	81
c*	49	73 PINTO	NTNGTA		1700	3765	41	35	110	116	263	154	28	16	5	30	13	1.1	0.9	26	82	79
c*	47	71 BLANCO	COMITÉ		1700	3169	42	36	117	125	304	191	20	17	5	19	13	1.1	0.9	29	79	77
c*	31	49 BLANCO	NTBLTA		2100	3372	46	38	106	116	243	132	28	16	4	35	12	1.1	1.0	22	85	76
c*	103	150 BLANCO	OLOTÓN	OLOTÓN	1860	3763	42	35	118	125	293	174	21	20	5	31	13	1.1	1.0	29	76	76
c*	135	190 BLANCO	NTBLTA	QUICHE	1760	3103	39	31	112	119	260	151	21	18	4	30	10	1.1	1.0	24	80	76
c*	87	125 BLANCO	OLOTÓN		2170	3383	41	37	111	119	287	172	28	16	5	35	16	1.1	0.9	24	82	72
d*	190	267 AMARILLO	NTAMTA	QUICHE	2050	3074	45	38	111	118	246	140	19	17	4	37	12	0.9	0.9	24	79	73
e*	225	317 AMARILLO	OLOTÓN		N.A	4194	39	36	114	119	301	176	24	19	5	22	12	1.0	1.0	27	78	100
e*	218	305 BLANCO	OLOTÓN		N.A	3807	47	42	110	114	238	131	23	15	4	31	10	0.9	1.0	23	81	91
e*	221	310 BLANCO	OLOTÓN		N.A	3853	40	35	118	124	311	189	17	19	5	15	11	1.0	1.1	33	75	91
e*	228	322 BLANCO	OLOTÓN		N.A	4082	46	40	115	121	291	183	25	18	5	19	11	1.0	1.1	32	73	85
e*	231	325 BLANCO	OLOTÓN		N.A	3879	45	35	118	124	310	195	31	19	5	18	11	1.0	1.0	29	74	84
e*	227	320 AMARILLO	OLOTÓN		N.A	3668	43	37	115	120	299	186	28	19	5	27	10	1.0	1.1	26	78	80
e*	224	313 AMARILLO	OLOTÓN		N.A	3237	42	38	122	127	312	194	24	18	4	16	11	0.9	1.0	30	73	75
e*	230	324 AMARILLO	OLOTÓN	OLOTÓN	N.A	3438	44	35	118	127	314	201	25	18	5	29	12	1.0	1.0	27	74	74
e*	222	311 PINTO	OLOTÓN		N.A	3621	38	31	114	120	285	166	29	19	5	26	11	1.0	1.1	29	75	72
		MEAN				2626	42	36	112	119	257	150	28	16	5	42	12	1.0	1.0	29	79	41
		LSD5%				1042	7	7	5	6	30	24	18	3	0	22	2	0.2	0.1	7	6	
		C.V.				20	8	10	2	3	6	8	34	8	4	26	7	8	7	13	4	

ALT = Altitude; YLD = Yield; GE = Germination; PP = Number of plants; AN = Anthesis (days to male flowering)
SI = Silking (days to female flowering); PH = Plant height; EH = Ear height; LD = Lodging; EL = Ear length
ED = Ear diameter; ER = Ear rot; KRN = Kernel row number; KL = Kernel; KW = Kernel width
MO = Moisture; SH = Shelling; SEL = Selection index [SEL = YLD x (1 - ER/100)/3323 x 100 + (100-LD) – 2.8 x MO]
N.A. = Not Available

Figure 4. Phenotypic diversity of 238 accessions from Mazateca, Cuicateca, and Mixe in the northern highlands of Oaxaca, Mexico.



Local Seed Production and Distribution and Implications for Conservation

To encourage in situ conservation of local maize races, farmers should be able to access improved accessions that represent the diversity of those races. A new seed bank (inaugurated in 2001) located at INIFAP's Central Valley of Oaxaca experimental station holds 1000 accessions of maize, 282 accessions of beans (*Phaseolus vulgaris, P. coccineus,* and *P. polyanthus*), and 104 accessions of squash (*Cucurbita pepo, C. ficifolia, C. moschata,* and *C. argyrosperma*). These accessions are maintained in medium-term storage at 4°C with controlled relative humidity (35%).

Since INIFAP and CIMMYT began collaborating on in situ conservation of Oaxacan maize races in 1997, they have organized many field demonstrations for consultation with farmers. The INIFAP-CIMMYT collaboration has provided more than 8 t of improved seed to farmers. It has also organized seed fairs, where farmers bring seed of their maize, bean, chile, squash, and *quelite* varieties to facilitate seed exchange. The project has contacted more than 2,000 farmers for participatory local maize improvement, seed production, and distribution in the Central Valley, Mazateca, Cuicateca, Mixe, Istmo de Tehuatepec, and coastal regions in Oaxaca (Figure 1).

Throughout Oaxaca, there is a marked preference for local maize races over commercial hybrids. Farmers continue to select seed of their local varieties cycle after cycle, selecting mainly on the basis of desired ear and grain types (Bellon et al. 2003; Louette et al. 1997; Louette and Smale 1996) and allowing possible introgression of other germplasm sources. The in situ conservation research described here seeks a way for scientist-breeders to contribute in a positive way to farmer-breeders' traditional seed maintenance and improvement (Eyzaguirre and Iwanaga 1996; Brush 1995). The breeders' knowledge of agronomic traits in elite and local landrace germplasm can help improve farmers' varieties. Gaps in the ex situ collection can be filled as samples are collected more systematically, to support participatory improvement of economically important local maize races. For example, it was apparent that some of the intra-racial genetic diversity identified in these studies had not been conserved in the INIFAP and CIMMYT maize germplasm banks. It seems important to conserve this diversity ex situ because it represents potentially useful genotypic variation in the race complexes.

The core subsets of races used in the in situ conservation project have been a valuable addition to the ex situ collection. These accessions can be used if original variations of the landraces are needed—for example, if local maize experiences inadvertent gene flow from commercial seed sources such as hybrids with transgenes or from other diverse germplasm sources.

Conclusions

A successful formal breeding program starts with well-characterized germplasm that can be used for selection and recombination. Decentralized breeding focuses on local genetic diversity as expressed in different seed types, different preferences of farmers, and specific adaptation to local growing conditions. The participatory, decentralized breeding approach described here depends on germplasm sources that are well characterized by breeders and farmers.

The in situ conservation project in Oaxaca began by studying the intra-racial diversity of local landraces to identify the best germplasm sources for enhancement. These studies made it possible to define core subsets of accessions representing intra-racial diversity in the Mexican maize races Bolita, Zapalote Chico, Tuxpeño, Olotillo, Tepecintle, and Olotón and related races. These subsets helped to fill a gap in the ex situ germplasm collection and will be a valuable resource for the future.

The genetic diversity of Mexican maize races will be conserved on-farm as long as farmers are willing to cultivate them. As described in this paper, participatory breeding can improve the social and economic value of landrace cultivars and encourage further in situ conservation. The local community seed bank and ex situ gene bank can support collaborative germplasm enhancement to benefit farmers. Similar in situ projects to conserve maize germplasm can be extended to other races in other parts of Mexico and Latin America.

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References

Aragón, F., E. Paredes, J.F. Ortega V, S.Taba, J. Díaz, H. Castro, and N. Dillánes R. 2000. Genetic diversity of the Milpa in the Mazateca, Cuicateca and Mixe zone from Oaxaca, Mexico. In G.F. Zavala, R. Ortega P., J.A. Mejia C., I.Benitez R., and H. Guillen A. (eds.), *Memorias del XVIII Congresso Nacional de Fitogenetica: Notas Cientificas SOMEFI*. P. 105. Irapuato, Gto., Mexico.

Brush, S.B. 1995. *In situ* conservation of landraces in Centers of crop diversity. *Crop Sci*. 35:346-354.

Bellon, M. R., J. Berthaud, M. Smale, J. A. Aguirre, S. Taba, F. Aragón, J. Díaz, and H. Castro. 2003. Participatory landrace selection for on-farm conservation: An example from the Central Valleys of Oaxaca, Mexico. *Genetic Resources and Crop Evolution* 50: 401-416.

Eyzaguirre, P., and M. Iwanaga. 1996. Farmers' contribution to maintaining genetic diversity in crops and its role within the total genetic resources system. In P. Eyzaguirre and M. Iwanaga (eds.), *Participatory Plant Breeding*. IPGRI, Rome, Italy. pp. 9-18.

Franco J., J. Crossa, J. Díaz, S. Taba, and S.A. Eberhart. 1997. A sequential clustering strategy for classifying genebank accessions. *Crop Sci*. 37: 1656-1662.

Franco J., J. Crossa, J. Villaseñor, S. Taba, and S.A. Eberhart. 1998. Classifying genetic resources by categorical and continuous variables. *Crop Sci*. 38:1688-1996.

INEGI. 2002. Anuario Estadístico Oaxaca, Tomo 1. Instituto Nacional de Estadística, Geografía e Informática, Mexico. p.478.

Louette, D., A. Charrier, and J.Berthaud. 1997. *In situ* conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community. *Economic Botany* 51(1): 20-38.

Louette, D., and M. Smale. 1996. Genetic diversity and maize seed management in a traditional Mexican community: Implications for in situ conservation of maize. NRG Paper 96-03. Mexico, D.F.: CIMMYT.

Ortega Paczka, R. 2003. La diversidad del maíz en México. En: Sin maíz no hay país. Consejo Nacional para la Cultura y las Artes/Dirección General de Culturas Populares e Indígenas. pp. 123-154.

SAGARPA. 2002. Anuario Estadístico de Producción Agrícola, Centro de Estadística Agropecuaria. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca, y Alimentación, Mexico.

SAS Institute Inc. 1996. SAS/STAT Software: Changes and enhancements through Release 6.11. Cary, NC.

Sánchez G. J. J., M.M. Goodman, and C.W. Stuber. 2000. Isozymatic and morphological diversity in the races of maize in Mexico. *Economic Botany* 54(1): 43-59.

Taba, S. 1998. Maize genetic resources and prebreeding. Annual research report of maize genetic resources, Mexico, D.F.: CIMMYT.

Taba, S., and J. Díaz. 1999. Maize genetic resources and prebreeding. Annual research report of maize genetic resources, Mexico, D.F.: CIMMYT.

Taba, S., F. Aragón, J. Díaz, H. Castro, and J.M. Hernández. 1998. Local maize cultivars for their conservation and improvement in Oaxaca, Mexico. In V Ramírez, F. Zavala G., N.O. Gómez M., F. Rincón S. y A. Mejía C. (eds.), *Memorias del XVII Congreso de Fitogenética: Notas científicas* SOMEFI. Chapingo, Mexico. p.218.

Taba, S., H. Remier, D. Duncan, and J. Díaz. 2000. Maize genetic resources and prebreeding. Annual research report of maize genetic resources. Mexico, D.F.: CIMMYT.

Wellhausen, E.J., A. Fuentes O., and A.H. Corzo, with P.C. Mangelsdorf. 1957. Races of maize in Central America. Pub. 511. NAS-NRC, Washington, DC.

Wellhausen, E.J., L.M. Roberts, and E. Hernández X., with P.C.Mangelsdorf. 1952. Races of maize in Mexico. The Bussey Inst., Harvard Univ. Cambridge, MA.

Wishart, D. 1987. CLUSTAN User Manual. 3rd Ed. Program Library Unit Univ. Edinburgh, Edinburgh.

Conservation and Use of Highland Maize Races in Chihuahua, Mexico

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Abstract

Highland maize races were collected in Tarahumara and Babicoras regions in the state of Chihuahua, Mexico. In 1998, these races were evaluated for plant and ear traits to study local maize diversity. Previously known races of maize from the regions were also collected as well as a few introductions and locally adapted races. Cristalino de Chihuahua, Azul, Apachito, Gordo, and Rosita are cultivated mainly in the highlands of Tarahumara and Babicoras. New and introduced races are Hembra, Tulancingo, Celaya, Cónico Norteño, Tuxpeño, and Pepitilla, and improved varieties like Compuesto Blanco and Cafime. A new race, Hembra, had been bred locally in cross combinations between Celaya, Cónico Norteño, Tuxpeno, and Cristalino de Chihuahua (or Perla), and it has become a productive local race. The representative accessions formed a core subset representing regional maize diversity, and seed samples were conserved in CIMMYT and INIFAP germplasm banks. Some of the best accessions were seed increased for distribution to the farmers.

Key words: In situ conservation, maize races, core subset, Cristalino de Chihuahua, Azul, Apachito, Gordo, Rosita, Hembra, Perla Amarilla, Perla Blanca.

Introduction

Maize production in the state of Chihuahua, Mexico, mainly relies on the use of adapted commercial hybrids under irrigation. However, rainfed maize production area still accounts for about 65% (118,000 ha) of the total maize acreage. The commercial hybrids produce 508,000 t of maize on about 66,000 ha, while rainfed maize produces 94,000 t (SAGARPA 2002). In the state of Chihuahua, there are many farmers who cultivate traditional landraces and a few improved varieties under rainfed conditions in the highlands of the maize growing regions.

Drought conditions in the north of Mexico during the last 12 years, the preference in the market for white maize for industrial quality, and the conditions of extreme poverty have influenced the availability and existence of native varieties. In the highlands in the state of Chihuahua, there are stress prone maize growing regions where no hybrid maize can be grown without irrigation. These regions are located in Tarahumaras and Babicoras, as well as other very dry and hot lowland areas where local landraces are mainly cultivated. In the high mountain regions of Tarahumara and Babicora, cool temperatures limit maize growing periods to 125 days, or even less if precipitation is limited. At lower elevations, very low annual precipitation does not allow a full season of improved maize varieties to be grown without irrigation. These maize growing regions in the state have developed specific maize races adapted to the soil and climatic conditions.

The regional formal breeding program developed additional maize germplasm by introgression and acclimatization of introduced germplasm from other regions of Mexico. The farmers often request that the maize breeders provide them with the seed of local maize races after a severe drought hits local maize production. Despite unfavorable maize growing conditions in these regions, farmers continue planting the local maize races as an integral part of their subsistence farming system. In other highland areas in Mexico, farmers apply similar maize germplasm conservation practices in terms of landrace seed management and utilization (Louette et al. 1997; Louette and Smale 1996; Bellon et al. 2003; Perales et al. 2003 a and b; Aragón et al. in the proceedings). Through the cultivation and maintenance by Mexican farmers, in situ conservation of maize races has been realized.

In 1998, seed samples were collected from local farmers in the highland regions of Chihuahua. Evaluation of the accessions was performed to obtain their patterns of phenotypic diversity. The racial classification of the accessions was made according to Wellhausen et al. (1952) and Xolocotzi and Alanís Flores (1970). The diversity among the accessions was measured by agro-morphological traits, and the best accessions were identified for selection and seed multiplication for farmers' use.

Adaptation and Use of Maize Races in the Highlands of Chihuahua, Mexico

In the highlands of Chihuahua, Tarahumaras (Raramuri) are the principal indigenous group. There are other indigenous groups like Tepehuanes (O'doqui), Pimas (O'ob) and Guarojios (Macarami), as well as mestizos in small communities. These indigenous groups have developed a subsistence farming system in which maize is a principal crop for food. It is cultivated on *maguechis*, small plots of less than three hectares, in the mountain ranges at about 2400 masl. Subsistence farming is carried out on about 34,000 ha, according to their traditional social and moral standards, and the so called-market economy is minimum or non-existent.

In the valley of La Alta Babicora in a village named Madera, located at an altitude of 2,200 masl, the climate is semiarid to temperate, with frequent snow or light rains during the winter (comprising of about 15% of the annual precipitation). The total annual precipitation is about 420 mm, which is sufficient to support a rainfed maize production system. The highland rainfed maize growing regions cover 55,000 ha where maize can be grown eight out of every ten years with a frost free period of 125 days. The traditional maize races of Apachito, Azul, Gordo, Cristalino of Chihuahua (locally called Perla Blanca and Amarillo), and Dulcillo del Noroeste are grown in the altitude range of 2,200 - 2,400 masl in Tarahumaras and Alta Babicora using traditional farming practices.

Another eco-geographical maize-growing region between La Alta Babícora and Cuauhtémoc-Guerrero-Temosachic, at an altitude of 2,000 masl, has even less annual precipitation amounting to only 386 mm. This region is called La Baja Babicora. Farmers are able to plant maize about 50% of the time. The local varieties are resistant to drought and are derived from crosses of Cristalinos de Chihuahua with introduced races such as Cónico Norteño, Celaya, and Tuxpeño. The farmers call these local races *maíz hembra*. The other varieties are Pepitilla (white and yellow), Tulancingo (white and yellow), and Blanco Independencia (Tuxpeño type). Rainfed maize is grown on about 20,000 ha in this area.

Another maize growing region is called General Trías-Satevo, located in a hot, dry region at an altitude between 1,300 and 1,600 masl. The summer rainy season unleashes a precipitation of 350 mm. It is not a suitable region for maize growing, but farmers plant maize by July using local maize called Maíz bonito, Olote colorado, Cacareño, Catarineño, Tayahui, and germplasm of Cónico Norteño and Tuxpeño races. The region covers about 7,500 ha, and no samples have been collected in this region.

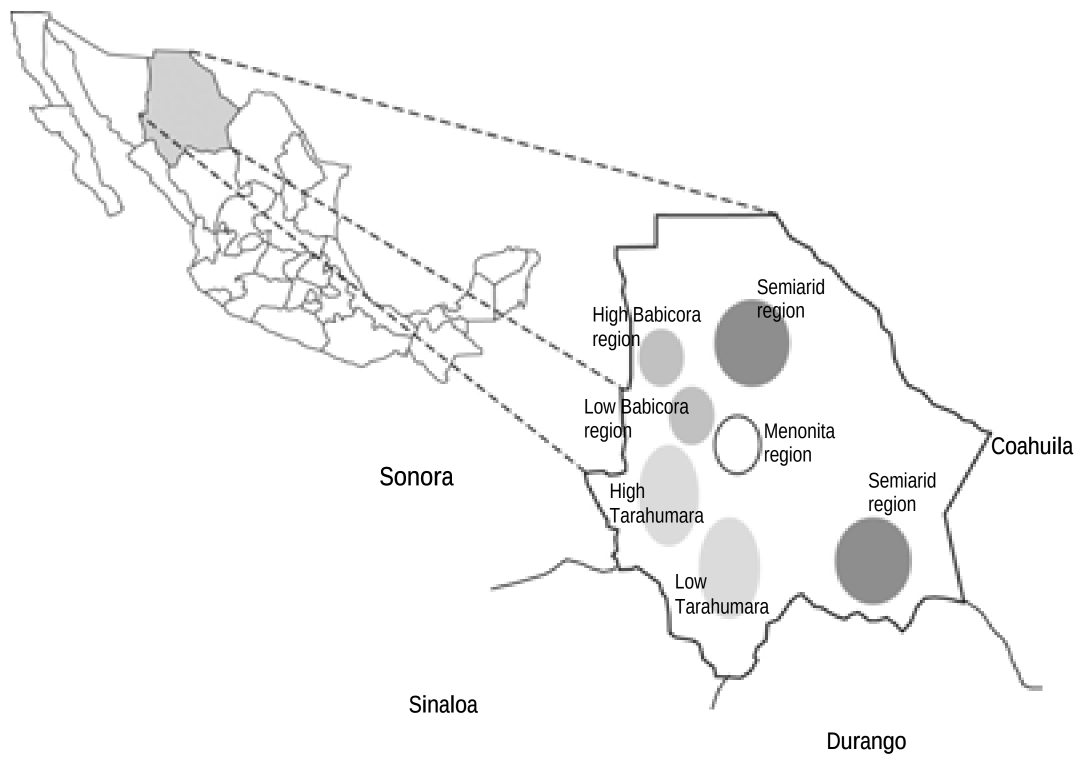
In the highlands of Chihuahua, farmers plant maize to produce food for human consumption and forage intended for livestock animals used for subsistence farming and transportation. Farmers are able to sell their products in the local market when the rain is adequate enough to produce the local maize. Any investment in farming is difficult because of lack of resources. They use local varieties and organic manure, and some use chemical fertilizers and fuel for a tractor.

In recent years, homemade tortillas from *nixtamal*, the Cristalinos de Chihuahua maize race grown in the high altitude region have declined; instead tortillas from commercial tortilla makers in the communities are purchased. When the Conasupo (government food agency) purchased maize, the farmers produced their preferred maize varieties for marketing. They grew *nixtamal* and a Hembra variety that is drought resistant and grown in the mid altitude region. Other maize races used by the farmers for special purposes are Azul, Gordo, and Apachito.

Blue Maize

The indigenous groups believe this maize has better nutritional quality—perhaps with a high protein content. It is used for making *pinole*, a toasted, floured, and energy providing snack food. In recent years, this blue, floury, long eared maize has been exported from Alta Babicola to the Rocallosa area in the USA.

Figure 1. Maize growing regions in the state of Chihuahua, Mexico.



Maíz Gordo

This variety is maintained and produced in an isolated plot to avoid pollen contamination from other maize. It is used for preparing a cracker called *harinillas* during Holy week. This maize flour can cost $7.50 Mexican pesos per kilogram.

Apachito

This race matures very early and is now almost extinct. Its characteristics can be seen in the cross combination with the race Cristalino de Chihuahua. It is called maize Rosita, which is used for preparing the fermented drink *tesguino*.

These farmers follow a vegetarian diet and consume maize as their main food, complemented by beans, peas, squash, and *quelites*. Maize dishes are *atole*, tortillas, pinole, and tesguino. For religious and ceremonial purposes, the farmers take some ears, or *elotes*, to the church as gratitude to their God for the harvest. During Lent, all people in the communities, indigenous and mestizos (Chabochis) prepare a dish called *chacales*, which is made from dried maize grains.

Adaption of Local Maize Races

Adaption of maize races in stressed environments in Chihuahua is shown in Table 1. Maize cultivation reflects adaptation to the environment and to human culture and socio-economic needs.

Table 1. Local maize races and their adaptation to the stress prone regions in the state of Chihuahua, Mexico.

Region	Alt. (masl)	Climate	Maize race				
			Name	Type	Texture	Use	Ha*
High Babicora	2200	$C(w_1)(x')(b')(e)$[1]	Perla Bco. Perla amar. Azul Gordo Dulce Rosita	Early Early Early Intermediate Early Early	Corneo Corneo Harinoso Harinoso Amilaceo Corneo	T T T T E T	29,000
Low Babicora	2000	$BS_1Kw(w)(e)$[2]	Temporalero Pepitilla amar. Tulancingo Bco. Tulancingo amar Hembra Argentino Celaya Tuxpeño Mex. de junio	Very early Intermediate Intermediate Intermediate late late late late late	Semi-flour Semi-flour Semi-flour Semi-flour Semi-flour Semi-flour Semi-flour Semi-flour Semi-flour	T. T,M T, M T,M T,M T,M n.a n.a T	32,000
High Tarahumara	2400	$C(w_2)(x')b(e)$[3]	Azul Gordo Apachito Rosita Perlilla de la sierra Dentado serrano	Early Intermediate Very early Early Early Early	Flour Flour Corneous Corneous Corneous Semi-flour	T T t T T T	29,000
Low Tarahumara	700	n. a.	Chopo Ocho carreras	n.a. n.a.	Semi-flour Semi-flour	T T	15,000
Gral. Trias satevo	1300	$BS_1K''w(w)(e)$[4]	Bonito Catarineño Temporalero Olote colorado Cacareño Tayaui	Early Intermediate Very early Early Intermediate Late	Semi-flour Semi-flour Semi-flour Semi-flour Semi-flour Semi-flour	T,M T,M T,M T,M T,M T,M	8,500

n.a.=Not available; T=Tortilla; t=Tesguino (flour); M=Market; E=Elote (green ear)

1 = Temperate-semidry with 420 mm rains in summer and some winter precipitation.
2 = Semidry with 386 mm rains in summer and little winter precipitation.
3 = Temperate-sub-humidity with 450 mm rains in summer and some winter precipitation.
4 = Semidry-hot with 350 mm rains in summer and little winter precipitation.
* SAGARPA 2002.

On-farm Seed Management

There is no commercial store or regional seed industry where farmers can buy seed, and it is particularly difficult to acquire seed when there is a drought or frost. The problem of obtaining seed is complicated since there are no varieties available in the world adapted to the eco-geographical conditions found in the highlands of Chihuahua. Some researches have tried to introduce new varieties to the region but have failed.

In November-December, the farmers harvest maize and store the ears in *trojes*. Usually there are no problems encountered with insects during grain storage before planting. Farmers then prepare the seed, selecting the best ear types true to the varieties that they want.

From the passport data of 203 accessions, collected in 1998 (Table 2), it was found that 80% of farmers planted their own seeds, keeping the distinctive traits of the varieties, 12% planted a mixed seed lot with other varieties, 6% planted local varieties from other farmers in the same region, and 2% planted improved varieties. The passport records show that 30% of farmers have retained their varieties for more than 50 years and 50% have conserved and used their seed for more than 25 years. In the last decade there was a remarkable amount of seed exchange and use due to improved, introduced, and mixed seeds. Córdova (1992) reported that 39% of farmers planted their own seed, 28% of them interchanged or mixed their seeds with other farmers, and 33% bought the seed from other farmers in the same region.

Table 2. The seed sources retained by farmers in the region of Chihuahua, based on the passport data of 203 accessions collected by INIFAP - CIMMYT in 1998.

Seed sources	Percentages of the varieties have been retained by the farmers from each decade to the present					Total
	1950	1960	1970	1980	1990	
Farmer	30	3	16	4	27	80
Mixed	2	0	1	2	7	12
Introduced	0	0	0	0	6	6
Improved	0	0	0	0	2	2
Total	32	3	17	6	42	100

Race Classification of the Accessions Collected in 1998

Race classification was performed during evaluation of the 203 accessions collected in 1998. Based on Wellhausen et al. (1952) and Xolocotzi and Alanís Flores (1970), we found that 79 accessions were local maize races, 110 accessions were those introduced from other regions of Mexico, and 14 were improved maize varieties (Table 3). We found some accessions of interracial mixtures, judged from segregating ears in the evaluation trial at El Batán, CIMMYT. Compuesto Blanco, an improved variety developed at the INIFAP experimental station at CESICH, Chihuahua, is composed of the local Cristalino de Chihuahua germplasm introgressed with germplasm accessions of other Mexican highland materials that belong to Cónico Norteño, Chalqueño, and Bolita races. It has good standability even at harvest, a desirable trait for the farmers, and satisfactory grain quality when compared to local races. Another improved variety, Cafime, was developed from accessions of the race Bolita collected in the Central valley of Oaxaca (Ortega P. et al. 1991).

Table 3. Race classifications of 203 accessions at El Batán, CIMMYT, 1998.

Local maize races	No of samples collected	Percentage of the race accession in the total
Indigenous races		
Cristalino de Chihuahua	33	25.61
Cristalino de Chihuahua mixed	19	
Azul	17	8.37
Gordo	6	2.95
Apachito	2	0.98
Rostias (Apachito with Christ. Chihu.)	2	0.98
Introduced races from other regions of Mexico.		
Celaya	4	16.25
Celaya (Hembra)	27	
Celaya (mixed)	2	
Cónico Norteño/Hembra (Jimulco)	3	23.64
Cónico Norteño	21	
Cónico Norteño (red)	5	
Cónico Norteño (Tulancingo)	19	8.37
Tablilla de ocho	15	
Tablilla de ocho mixed	2	4.92
Pepitilla	10	0.98
Dulcillo del Noroeste	2	
Improved varieties		
Compuestos Blanco (includes germplasm of Cónico Norteño, Chalqueño, Bolita, Cristalino de Chih.)	10	4.92
Cafime (from Bolita)	4	1.97

Farmers' Selection Criteria for the Preferred Maize Races

The farmers identify the following morphological characteristics of the local races: ear size and form, kernel row number, grain type, grain texture, and grain color. They group them into early, intermediate, and late types. Soft husks are considered a desirable characteristic of the local maize races. They prefer varieties that can avoid drought and early frost in September and have thin cobs to facilitate manual grain shelling. In addition, seed quality for the local dishes such as tortillas, tesugino, pinoles, and harinillas is important for the preferred maize types. Ninety-four percent of the farmers gave their variety to the collectors and recognized that local maize has a problem of plant lodging at the time of harvest. The improved variety known as Compuesto Blanco has better standability at harvest than the local maize races. This is one of the reasons farmers have accepted the variety, despite having a larger cob size and a hard grain type. Cafime was introduced to the region as a drought resistant variety but has not spread widely even though INIFAP distributed the seeds for about 40 years. Farmers seem to give high priority to grain quality as well as agronomic traits such as earliness, cold tolerance, drought resistance, and standability (resistance to plant lodging). With the genetic erosion that has taken place in this region and the restricted number of local varieties available, farmer ability to respond to different adverse conditions is limited. However, from the 203 accessions collected, we found most maize races to be represented, as reported previously by Wellhausen et al. (1952) and Xolocotzi and Alanís Flores (1970). Cristalino de Chihuahua and Azul have evolved to fit the very short, cool growing seasons experienced in Tarahumaras and Alta Babicora at the high elevations of 2400-2500 masl (Xolocotzi and Alanís Flores 1970). The races Cristalino de Chihuahua and Azul have good yield potentials with long, cylindrical ears and a profused tillering capacity when grown at El Batán, Mexico.

Choosing a Breeder Subset of the Accessions for Selection and Multiplication

In March 1998, 203 accessions were collected in the high elevation regions of Taraumaras and both high and low elevation regions of Babicolas in the state of Chihuahua, Mexico. Including 37 CIMMYT bank accessions previously collected from the same regions, 5 evaluation trials of 240 entries were conducted at El Batán (CIMMYT, 2200 masl), Porvenir del Campesino Gomes Farias (high Babicola, 2200 masl), Campo Menonita 1-A Cuauhtémoc (low Babicola, 2000 masl), Sto. Tomas Guerrero (low Babicola, 2000 masl), and Bachiniva Chihuahua (low Babicora, 2000 masl). The experimental design was 15 x 16 (0,1) alpha lattice with two replications. Plot size was two rows, each 5m long with 32 plants. The rate of N-P-K fertilizer application at all sites in the state of Chihuahua was 80-40-0 kg/ha. At El Batán application was 150-40-0 kg/ha.

The data on plant and ear traits: plant height (PH), ear height (EH), days to silk (SI), days to anthesis (AN), ear diameter (ED), ear length (EL), kernel row number (KRN), kernel length (KL), kernel width (KW), seed moisture % (MO), number of leaves above ear (LAE), ears per plant (EP), and grain shelling % (SH) were used for a multivariate cluster analysis as described by Franco et al. (1998). Other data on grain yield (YLD), root (RL) and stalk (SL) lodgings, ear quality (EQ), ear rot % (ER), tillering (TI), agronomic sale rating (AGS), easiness of shelling (ESY), and plants harvested (PHV) were also recorded, to construct a selection index for agronomic performance.

The cluster analysis formed eight non-overlapping clusters, indicating the extent of phenotypic diversity among the accessions. Figure 2 shows the patterns of variation based on canonical discriminant analysis (PROC CAN DISC, SAS 1996) on 13 plant and ear traits as used for the cluster analysis. Selection index (SEL) was calculated by yield (kg/ha) x (1-% ear rot/100)/4329 x 100 + (100-% standability) – 4.55 x % grain moisture. A core subset of the best 20% of the accessions (48 accessions) representing phenotypic diversity among the clusters was chosen using selection indices (Table 4). The core concept was used to represent the genetic diversity present in large numbers of the germplasm accessions (Brown 1995). A breeder core subset was chosen based on agronomic traits that the farmers wanted, and phenotypic diversity of plant and ear types was based on the cluster analysis (Franco et al. 1998; Brown and Spillane 1999). The core subset included maize races of Cónico Norteño, Perla (Cristalino de Chihuahua), Celaya, Hembra, Perla (Christalino de Chihuahua) Blanco and Amarillo, Azul, Tablilla de Ocho, Apachito, Gordo, Dulcillo de Noroeste, Pepitilla, Argentino (a race type of Celaya), Tuxpeno (introduced variety), Cafime (improved variety of Bolita), and Monarca (early introduced hybrid from France). Cónico Norteño, Celaya, and Hembra had high yield potentials compared to the others. Hembra is a racial hybrid between Cristalino de Chihuahua (flint grained, long narrow ear) and Cónico Norteño or Celaya (thick dent ear type). Wellhausen et al. (1952) described Celaya, Tuxpeno, Cónico Norteño, Dulicillo de Norte, Pepitilla, and Argentina (a race type of Celaya), among the maize races encountered in this study. Xolocotzi and Alanís Flores (1970) described Apachito, Azul, Tablilla de Ocho, Gordo, Rosita, and Bofo from the Sierre Madre Occidental, Mexico; the first four races were collected in the highlands of Chihuahua (Table 4). Sánchez et al. (2000) studied all Mexican maize races, except the interracial crosses of Hembra and Rosita, for the genetic diversity of 21 enzyme loci and measured 47 morphological characters.

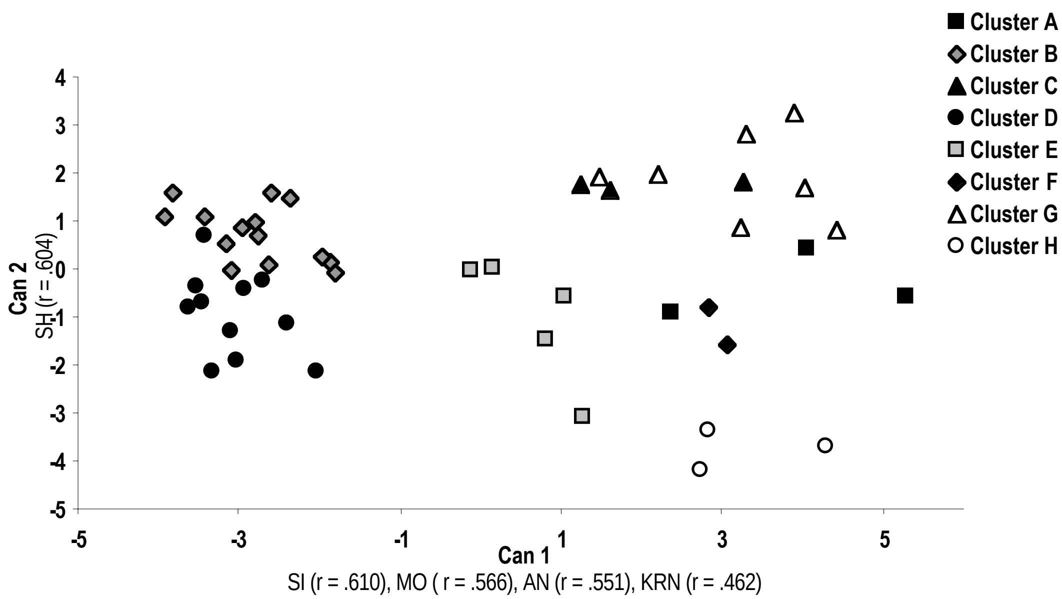
Table 4. Selected 48 accessions of a breeder core subset representing the phenotypic diversity of 240 germplasm accessions evaluated at five locations in 1998.

Cluster	Entry	ID Number	Accession	Race 1	Race 2	ALT	YLD	PP	AN	SI	PH	EH	LD	EL	ED	ER	KRN	KL	KW	ADP	AGS	MO	SH	SEL
							kg/ha				cm	cm	%	cm	cm	%		cm	cm	1_5	1_5	%	%	%
a*	172	21133	CHIH 494	CONNOR		2100	6024	30	76	83	264	117	7	18	4.9	31	18.4	1.2	0.7	2	3	26	82	70
a*	221	21126	CHIH 487	CONNOR	HEMBRA	2010	5432	28	75	82	252	113	10	19	4.9	27	15.2	1.2	0.8	2	3	26	82	63
a*	78	21155	CHIH 516	CONNOR	FASCIA	2010	6304	29	78	83	252	117	20	17	5.2	31	20.6	1.2	0.7	3	3	26	83	61
b*	38	21021	CHIH 382	PERLA		2230	5520	33	66	71	223	81	14	21	3.8	28	11.8	1.0	0.7	2	3	18	84	96
b*	47	21043	CHIH 404	HEMBRA		2250	5205	28	65	68	212	73	17	21	4.0	30	12.8	1.0	0.8	3	3	17	85	91
b*	97	21191	V-33	PERLA		N.A.	4805	30	60	65	192	61	13	19	4.1	32	13.4	1.0	0.8	3	3	16	83	90
b*	88	21170	CHIH 531	PERLA		2010	6029	32	67	72	236	85	11	20	4.2	30	12.2	1.1	0.8	2	3	21	81	89
b*	43	21030	CHIH 391	PERLA		2250	4689	28	63	69	211	71	15	20	3.9	28	10.6	1.0	0.8	3	3	16	85	89
b*	109	20999	CHIH 360	AZUL		2230	5481	32	65	69	213	81	16	21	4.1	34	11.4	1.0	0.8	3	3	18	84	85
b*	106	20996	CHIH 357	AZUL		2230	5028	29	66	70	215	77	18	20	4.0	35	12.0	1.0	0.8	3	3	16	84	85
b*	90	21175	CHIH 536	PERLA		2010	4923	28	64	68	213	76	16	19	3.9	31	12.0	1.0	0.8	3	3	17	84	84
b*	64	21082	CHIH 443	PERLA		2000	4958	32	67	72	229	85	13	21	3.8	32	10.4	1.0	0.8	3	3	18	84	83
b*	138	21061	CHIH 422	PERLA		2250	4650	29	63	67	206	66	11	20	4.0	32	12.4	1.0	0.8	3	3	18	84	82
b*	142	21069	CHIH 430	AZUL		2250	5310	30	66	71	228	85	22	21	4.1	31	12.0	1.0	0.8	3	3	18	83	82
b*	53	21052	CHIH 413	TABLI8		2230	4972	32	63	68	212	70	21	20	3.7	30	9.4	1.1	0.9	3	3	17	86	82
b*	48	21045	CHIH 406	PERLA		2250	5448	29	65	70	215	74	12	20	4.1	39	12.6	1.0	0.8	3	3	18	85	81
b*	59	21067	CHIH 428	PERLA		2250	5050	30	65	70	219	74	16	21	3.9	30	11.4	1.0	0.8	3	3	19	83	81
c*	195	21193	COMP. BCO.	CONNOR		N.A.	5657	32	70	76	234	91	2	16	4.5	26	15.1	1.2	0.7	3	2	25	85	82
c*	128	21039	CHIH 400	CONNOR		2250	5476	30	67	71	230	91	9	18	4.5	37	14.8	1.1	0.7	3	3	20	87	82
c*	127	21038	CHIH 399	COMPBL		2250	5085	30	65	70	232	95	9	17	4.5	35	15.0	1.1	0.7	2	3	19	84	79
d*	103	20993	CHIH 354	AZUL		2230	5873	33	66	70	219	77	16	21	4.1	36	13.0	1.0	0.8	3	3	16	81	100
d*	22	6863	CHIH 255	AZUL	PERLA	1800	5021	29	65	70	210	71	13	19	4.1	30	13.0	1.1	0.8	3	3	15	81	99
d*	129	21041	CHIH 402	AZUL		2250	5437	31	66	71	222	85	12	20	4.1	34	12.0	1.0	0.8	3	3	16	82	98
d*	96	21190	CHIH 551	PERLA		2230	5133	28	64	68	220	75	13	22	4.0	32	11.6	0.9	0.8	3	3	17	80	90
D*	25	7933	CHIH 129	PERLA		2095	4721	27	63	66	191	61	9	19	4.0	34	12.4	1.0	0.8	3	3	16	83	88
D*	8	6778	CHIH 156	PERLA		2140	4756	29	62	66	192	62	13	21	4.4	30	14.4	1.0	0.8	3	3	17	81	88
D*	147	21078	CHIH 439	AZUL		2000	4990	30	65	70	229	80	12	21	4.2	35	12.2	1.0	0.8	3	3	17	83	87
D*	148	21079	CHIH 440	CONNOR		2000	5143	26	67	72	230	84	9	21	4.1	34	12.4	1.1	0.8	2	3	18	83	87
D*	110	21000	CHIH 361	PERLA		2230	5006	30	66	71	228	83	13	20	4.1	33	11.6	1.0	0.8	3	3	17	81	87
D*	125	21034	CHIH 395	AZUL		2250	5072	30	65	69	219	79	13	20	4.1	40	11.6	1.0	0.8	3	3	16	83	86
D*	130	21042	CHIH 403	AZUL		2250	4905	28	63	68	219	81	15	20	4.2	33	13.4	1.1	0.8	3	3	17	83	85
e*	72	21113	CHIH 474	CELAYA	PERLA	2010	5589	29	74	80	248	111	11	20	4.4	27	13.5	1.1	0.8	2	3	23	79	79
e*	184	21151	CHIH 512	PERLA		2010	5453	29	72	79	247	105	6	19	4.5	30	13.8	1.0	0.8	2	3	23	80	79
e*	18	6853	CHIH 244	CONNOR		1900	5131	31	72	77	233	96	10	18	4.0	33	13.4	1.0	0.7	2	3	21	82	73
e*	237	21196	PERLA TEM	PERLA		N.A.	4747	27	70	75	229	83	9	20	4.1	29	12.8	1.0	0.8	3	3	22	82	70
e*	178	21140	CHIH 501	CONNOR		2100	5755	28	74	80	262	113	15	21	4.5	31	14.4	1.2	0.8	3	3	24	82	69
f*	105	20995	CHIH 356	CONNOR	GORDO	2230	5807	31	74	81	233	110	9	18	4.5	33	14.4	1.1	0.7	2	3	21	83	85
f*	56	21057	CHIH 418	DULNOR		2250	4193	30	71	76	206	77	13	16	4.2	28	15.6	1.1	0.7	3	3	17	86	78
g*	77	21149	CHIH 510	CONNOR		2010	4870	28	73	80	249	116	12	18	4.4	26	16.6	1.2	0.6	3	3	23	87	66
g*	152	21085	CHIH 446	CONNOR		2000	4934	29	69	76	234	101	5	17	4.4	34	14.4	1.1	0.7	2	3	23	86	66
g*	89	21174	CHIH 535	CONNOR		2010	5115	29	72	77	242	97	7	19	4.4	29	13.0	1.1	0.7	2	3	25	84	62

g*	183	21150	CHIH 511	CONNOR	2010	4957	29	72	80	245	106	7	17	4.5	27	14.2	1.1	0.7	3	3	25	83	61
g*	229	21161	CHIH 522	CONNOR	2010	5489	30	75	81	262	122	14	18	4.5	30	17.0	1.1	0.7	3	3	25	84	60
g*	92	21179	CHIH 540	PERLA	2010	5379	29	70	77	239	99	13	19	4.1	36	13.0	1.1	0.7	3	3	24	83	59
g*	94	21184	CHIH 545	COMPBL	2010	4541	28	70	76	223	89	9	18	4.2	29	14.0	1.1	0.7	2	3	24	83	57
h*	196	21194	MONARC	MONARC	N.A.	4697	31	68	73	183	63	2	16	4.4	29	13.4	1.0	0.8	2	3	22	81	75
h*	155	21092	CHIH 453	CELAYA	1825	5920	32	78	83	248	115	14	18	4.9	30	13.4	1.1	0.8	2	3	27	80	61
h*	206	21088	CHIH 449	CONNOR	1825	5754	29	83	90	265	129	11	19	4.9	28	13.8	1.1	0.8	3	3	30	81	50
			Mean			**4914**	**28**	**70**	**75**	**230**	**91**	**12**	**19**	**4.3**	**34**	**13**	**1.1**	**0.8**	**3**	**3**	**22**	**83**	
			LSD5%			**1890**	**9**	**5**	**6**	**33**	**25**	**4**	**4**	**0.6**	**24**	**4**	**0.2**	**0.2**	**1**	**1**	**6**	**7**	
			C.V.			**20**	**16**	**4**	**4**	**7**	**14**	**9**	**10**	**7.6**	**36**	**14**	**9.1**	**10.7**	**18**	**18**	**15**	**4**	

ALT = Altitude; YLD = Yield; N.A. = Not Available; PP = Number of plants; AN = Anthesis (days to male flowering)
SI = Silking (days to female flowering); PH = Plant height; EH = Ear height; LD = Lodging; EL = Ear length
ED = Ear diameter; ER = Ear rot; KRN = Kernel row number; KL = Kernel; KW = Kernel width
MO = Moisture; SH = Shelling; SEL = Selection index [SEL = YLD x (1 - ER/100)/4329 x 100 + (100-LD) – 4.55 x MO]

Figure 2. Patterns of the phenotypic diversity of 48 accessions by canonical discriminant analysis. Can 1 and Can 2 explained 58% and 21%, respectively.



Selection of the Desired Plant and Ear Type for Seed Production and Distribution

All accessions collected in 1998 were seed increased at El Batán, CIMMYT, in the following year. Each accession was planted in 16 rows, each 5m long. Full-sib chain crosses were made for each accession, and at harvest clean pollinated ears were selected for *ex-situ* conservation. We selected 20-95 full-sib ears of the best 12 accessions among the core subset and planted them in separate plots for another cycle of full-sib chain crosses, for selection and seed increase at CIMMYT's Tlaltizapan station in the winter cycle. In 1999, the bulked seed of the full-sibs, for each of the best 12 accessions, were sent to INIFAP-Chihuahua to plant as foundation seed. Chih. 449, 453, and 516 accessions were produced in isolation on-farm with the cooperator farmers in Guerrero and Bachiniva, and 3.2 t of the seed were distributed to farmers in 2000. Controlled seed selection and production has been practiced every year to improve the best accessions. Table 5 shows the core accessions selected for in situ conservation at this stage, for the highlands of the state of Chihuahua, Mexico.

Table 5. Selected landrace accessions for seed multiplication in 1999.

No.	Accession	Race	Alt. (masl)	Ears selected for seed multiplication	Initial seed quantity (kg)
1	Chihuahua 354	Azul	2230	92	4.1
2	Chihuahua 356	Cónico Norteño	2230	30	3.0
3	Chihuahua 449	Cónico Norteño	1825	29	5.2
4	Chihuahua 453	Celaya	1825	19	4.9
5	Chihuahua 474	Celaya	2010	29	3.1
6	Chihuahua 487	Cónico Norteño	2010	95	2.7
7	Chihuahua 494	Cónico Norteño	2100	17	3.2
8	Chihuahua 501	Cónico Norteño	2100	87	2.3
9	Chihuahua 510	Cónico Norteño	2010	26	2.9
10	Chihuahua 512	Perla Blanca.	2010	28	1.8
11	Chihuahua 516	Cónico Norteño	2010	57	3.5
12	Chihuahua 531	Perla Blanca	2010	30	4.6
	Total			539	41.3

Discussion and Conclusion

In the state of Chihuahua, Mexico, maize is produced under irrigated and rainfed conditions. High yielding hybrids account for more than 81% of total maize production (627,000 t), while local maize races are grown with half of the input costs of hybrids and produce the remaining 19% of total maize production on more than 65% of the maize growing acreage of the state of Chihuahua (184,000 ha). The unique situation of maize cultivation in the state has maintained local maize races as part of the subsistence farming practices (Brush 1995) where maize is grown under sub-optimal climatic conditions (frequent drought and short frost free periods). The livelihood of the farmers is supported by the adapted landraces grown with minimum input costs. Similar situations, where traditional landraces are used on-farm, are reported in other highland regions of Mexico (Perales et al. 2003a and b; Aragón et al. in the proceedings; Taba et al. 1998). Farmers have maintained landraces, but intervention is needed by the formal breeding sector so that the farmers can conserve and enhance diversity while meeting their own needs.

In 1998, a total of 203 accessions were collected and seed was increased at El Batán, CIMMYT (2,300 masl). They were evaluated at both at El Batán, CIMMYT and four on-farm locations in Babicoras in the state of Chihuahua at 2000-2200 masl (Ramírez et al. 2000). Ear rot incidence was severe in the regeneration and seed increase plot in 1998. Using 13 agro-morphological traits, cluster analysis (Franco et al., 1998) was performed to cluster the accessions into 8 non-overlapping groups. A core subset of 48 accessions was chosen to represent the phenotypic diversity of the 203 accessions. The clean full-sib ears from the regeneration at El Batán, CIMMYT, from each of the best 12 accessions, were multiplied as foundation seed. They were planted again at CIMMYT's Tlaltizapan experimental station to obtain another cycle of full-sib selection. Then the cooperator farmers planted the breeder seeds of the best accessions in isolation. In 2000, the local breeders distributed 3.2 t of foundation seed to the farmers.

Simple mass selection or a modified half-sib ear to row selection (Lonnquist 1964) can be used to improve and maintain the best accessions every season. Clean ears of the race type acceptable to the farmers are selected from the seed increase plot and become the breeder seed for the next cycle. Other selected seed bulks will be used as foundation seed to be distributed to the farmers. The breeder seeds can be either bulked or planted in ear to row in the next year in a half-sib seed increase plot. The male rows are planted with a balanced bulk of the selected ears and the pollen can be controlled at the time of flowering by detassling undesirable plants. This mode of seed management can be operated by the local breeder with the help of farmers, while conserving and improving the maize germplasm in situ. Local seed banks can maintain and distribute the foundation seeds for in situ conservation and use. It is also possible to introgress desirable traits from other germplasm sources using a half-sib breeding procedure. CIMMYT gene pools have developed using a modified ear to row selection procedure, which is effective in improving yields and plant architecture (Taba and Díaz 1999). To optimize local maize improvement and encourage use of improved materials, it is recommended that collaboration between the local seed bank manager/breeder and the farmers be implemented for in situ conservation of useful maize races in Mexico. In situ conservation projects should benefit the farmers now and in the future by maintaining and enhancing the useful racial diversity of maize landraces. The maize germplasm used in situ conservation projects should also be conserved in ex-situ germplasm banks so that material can be properly stored and used in other germplasm development projects, thus allowing the incorporation of unique adapted genes.

References

Aragón, C.F., S. Taba, F.H. Castro-García, J.M. Hernández-Casillas, N.D. Ramírez, J.M. Cabrera-Toledo, L.O. Alcalá. 2005. *In situ* conservation and use of local maize races in Oaxaca, Mexico: A participatory and decentralized approach. In these proceedings.

Bellon, M.R., J. Berthaud, M. Smale, J. A. Aguirre, S. Taba, F. Aragón, J. Díaz, and H. Castro. 2003. Participatory landrace selection for on-farm conservation: An example from the Central Valleys of Oaxaca, Mexico. *Genetic Resources and Crop Evolution* 50: 401-416.

Brown, A.H.D. 1995. The core collection at the crossroads. In T. Hodgkin, A.H.D. Brown, T.J.L. van Hintum and E.A.V. Morales (eds.), *Core Collections of Plant genetics resources*. John Wiley Sons, Chichester, UK. pp. 3-19.

Brown, A.H.D. and C. Spillane 1999. Implementing core collections-principles, procedures, progress, problems, and promise. In R.C. Johnson and T. Hodgkin (eds.), *Core collections for today and tomorrow*. International Plant genetic Resources Institute (IPGRI), Rome, Italy. pp.1-9.

Brush, S.B. 1995. *In situ* conservation of landraces in centers of crop diversity. *Crop Science* 35: 346-354.

Córdova, B.A. 1992. Diagnóstico Agrícola (versión preliminar) Programa de Desarrollo Rural Integral de la Alta Babicora. Dirección General de Desarrollo Rural. Gobierno del Edo de Chihuahua. Pp.32-33. Documento de Trabajo no publicado.

Franco, J., J. Crossa, J. Villaseñor, S. Taba, S.A. Eberhart. 1998. Classifying genetic resources by categorical and continuous variables. *Crop Sci*. 38: 1688-1996.

Ortega P., R.A., J.J. Sánchez G., F. Castillo G., and J.M. Hernández C. 1991. pp 161-185. Estado actual de los estudios sobre maíces nativos de México. In R. Ortega P, G. Palomino H., F. Castillo G., V.A.González, H., M. Livera M. (eds.), *Avance en el estudio de los recursos fitogenéticos de México*. Sociedad Mexicana de Fitogenética, A.C. Apartado Postal 21, 56230, Chapingo, Mexico.

Lonnquist, J.H. 1964. A modification of the ear to row procedures for the improvement of maize populations. *Crop Sci*. 4: 227-228.

Louette, D., A. Charrier, and J. Berthaud. 1997. In situ conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community. *Economic Botany* 51(1): 20-38.

Louette, D., and M. Smale. 1996. *Genetic diversity and maize seed management in a traditional Mexican community: Implications for in situ conservation of maize*. NRG Paper 96-03. Mexico, D.F.: CIMMYT.

Perales R., H., S.B. Brush, and C.O. Qualset. 2003a. Landraces of maize in Central Mexico: An altitudinal transect. *Economic Botany* 57(1): 7-20.

Perales R., H., S.B. Brush, and C.O. Qualset. 2003b. Dynamic management of maize landraces in Central Mexico. *Economic Botany* 57(1): 21-34.

Ramírez, V.S., E. Díaz, S. J. Díaz, and S. Taba. 2000. Maize landrace collection, evaluation, and use in Chihuahua Highlands Mexico. In G.F. Zavala, R.Ortega P., J.A. Mejía C., I. Benitez R., y H. Guillén A. (eds.), *Memorias del XVIII Congreso Nacional de Fitogenética: Notas Científicas SOMEFI*. Irapuato. Gto, Mex. pp. 107.

SAGARPA. 2002. Análisis de los principales cultivos de Chihuahua, 1995-2002. INEGI, Gob. del estado de Chihuahua.

Sánchez, G.J.J., M.M. Goodman, and C.W. Stuber. 2000. Isozymatic and morphological diversity in the races of maize in Mexico. *Economic Botany* 54(1): 43-59.

SAS Institute Inc. 1996. SAS/STAT Software: Changes and enhancements through Release 6.11. Cary, NC.

Taba, S., and J. Díaz. 1999. Maize genetic resources and prebreeding. Annual research report of CIMMYT maize genetic resources. Mexico, D.F.: CIMMYT.

Taba, S., F. Aragón, J. Díaz, H. Castro, and J.M. Hernández. 1998. Local maize cultivars for their conservation and improvement in Oaxaca, Mexico. P. In V. Ramírez, F. Zavala G., N.O. Gómez M., F. Rincón S. y A. Mejia C. (eds.), *Memorias del XVII Congreso de Fitogenética: Notas científicas SOMEFI*. Chapingo, Mexico. p. 218.

Wellhausen, E.J., L.M. Roberts, and E. Hernández X., with P.C.Mangelsdorf. 1952. Races of maize in Mexico. The Bussey Inst., Harvard Univ. Cambridge, MA.

Xolocotzi, H.E., and G. Alanís Flores. 1970. Estudio morfológico de cinco nuevas razas de maíz de la Sierra Madre Occidental de México. *Agrociencia* 5 (1): 3-30.

Kernel Characteristics and Tortilla Making Quality of Maize Accessions from Mexico, the Caribbean, and South and Central America

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Abstract

Characterization of Latin American maize landraces for kernel characteristics and tortilla making quality should be useful for developing hybrids and varieties to ensure tortilla quality. A total of 224 bank accessions and several highland breeding pools from CIMMYT's maize genetic resources were evaluated for kernel traits such as kernel hardness, specific gravity (SG), weight of one thousand kernels (WT1000), kernel length, width and thickness, and for tortilla quality parameters such as water absorption capacity (WAC), masa yield (MY), tortilla yield (TY), tortilla weight loss during cooking (TWL), and cutting force. A Rapid Visco Analyzer (RVA) and a Differential Scanning Calorimeter (DSC) were used for testing starch viscosity and thermal properties (To, Tp, Tf and ΔH, respectively). Food use potential of the accessions for atole, tortilla, snack, pinole, and popcorn was estimated by weighted Euclidean distances. The variations of kernel and tortilla making quality traits of the accessions among Latin American countries were analyzed by principle component (PC) analysis. The PC analysis for kernel and tortilla quality traits for Mexican races as well as those from Central and South America and the Caribbean showed similar tendencies related to the final use. The maize races from Ecuador and Bolivia generally have a soft kernel texture, with high WAC and TWL. They are floury materials appropriate for thickeners and for making drinks. Other maize races with a hard endosperm (low WAC, MY, and TY) are found mainly in Colombia, Peru, Bolivia, and Chile. These races can be dry milled or used to make products like *arepas*, snacks, and nixtamalized flours. Most of the samples from the Antilles as well as those from Central America: Honduras, El Salvador, Panama, some from Guatemala; and from South America: Guyana, Surinam Brazil, Uruguay, and Paraguay, showed high WAC and low TWL. Although these are yellow corns, they can be used to make traditional tortillas. The races with high values for hardness and SG, low WT1000, and small kernels were mainly from Colombia, Guyana, Surinam, Peru, Chile, Argentina, Brazil and Guatemala are for making popcorn. The quality of different maize races related to WAC, TWL, and TY followed specific patterns that correspond to their geographical distribution.

Introduction

Corn is consumed in Mexico and Latin America in the form of tortillas and other products such as arepas, pinoles, atoles, tostadas, snacks, corn chips, tamales, corn on the cob, and many other foods. Of about 300 races of maize found on the American continent, about 50 are found in Mexico. Studies have generally classified and defined different races of maize from agronomic, cytologic, and taxonomic points of view. However, few studies have been done to evaluate their physiochemical, thermal, and quality characteristics. This is due to limitations such as sample size, cost, and the long processing times typically required to test corn quality, as well as the limited understanding of the importance of these kinds of studies on the part of many researchers. This also seems to be a recurring problem in most genetic improvement programs, which tend to ignore quality issues, although quality was the main concern of our ancestors in selecting and crossbreeding corn races. In several cases, large investments have been made on selection for agronomical yield, only to discover that the corn is of inferior quality for the end use. This key problem could have been identified early on so that operational costs could have been reduced significantly in breeding problems. Agronomical yield is frequently considered in isolation from quality, which can lead to serious losses of important material. The purpose of the present study was to classify maize races from Mexico, the Caribbean, South and Central America by their tortilla making quality, physiochemical, and thermal properties, by utilizing quick, simple, and relatively inexpensive non-conventional techniques. These techniques make it possible to overcome the obstacles evaluating tortilla making corn quality.

Materials and Methods

The genetic material studied consisted of 224 samples of 300 kernels of corn: 113 from Mexico and 111 from Central America, South America, and the Caribbean islands. The samples were from the CIMMYT collection.

All the genotypes were processed using ohmic cooking equipment for thermal testing and *masa* (dough) was obtained to test the following nixtamalization quality variables: water absorption capacity, masa and tortilla yield, and tortilla weight loss. The quality of the tortillas was evaluated without regard for color, since tortillas are made from colored maize in some cultures, and these tortillas are well accepted. The methods used to evaluate the physical kernel and tortilla quality characteristics are those reported by Arámbula et al. 1999 and Mauricio et al. 2004 (Table 1).

Principal Component (PC) analysis was carried out for kernel traits: hardness, specific gravity (SG), weight of one thousand kernels (WT1000), and the length, width, and thickness of the kernels, and for tortilla making quality traits: water absorption capacity (WAC), masa yield (MY), tortilla yield (TY), tortilla weight loss during cooking (TWL), and cutting force. A Rapid Visco Analyzer (RVA) and a Differential Scanning Calorimeter (DSC) were used for testing starch viscosity and thermal properties such as onset temperature (To), peak temperature (Tp), final temperature (Tf), and enthalpy (ΔH), respectively. Weighted Euclidean distances were used to design end use potentials (Mauricio et al. 2004).

Table 1 shows the final food use for some typical maize races (Hernández-X. 1972). This information helped to define the quality range used in the formula of Euclidian distances to compute automatically the end use potential for each specific maize race according to the procedure described by Mauricio et al. 2004.

Table 1. Relationship among several maize types and their uses for human consumption.

Maize races*	Final food use*	Some characteristics
Dulce de Jalisco, Dulcillo del Noreste, Chullpi (sugary)	*Pinole*, toasted whole kernel and milled, *chicha* or *tesgüiño (tejuino)* (fermented beverage) and ponteduro	Low viscosity, small enthalpy
Azules oscuros	*Tortillas* and *tamales* for special celebrations	Intermediate to smooth texture, low To, high MY, and TY
Elotes Occidentales, Elotes Cónicos, Maíz de Ecuaro (Mich.)	*Elotes (*corn on the cob), *Pozole*	Soft endosperm, low To
Cacahuacintle, Blandito de Sonora, Harinoso de Ocho (all floury).	*Pozole, Pinole,* Atoles	High viscosity, high WAC, MY and TWL
Zapalote Chico	*Totopos* and snacks	Intermediate to hard endosperm, low WAC and TY
Reventador, Chapalote, Palomero, Apachito, Arrrocillo Amarillo, Canguil	Popcorn, *Ponteduro*	Small kernels of very hard endosperm, low WT1000, high TWL and low WAC

* Hernández-X. 1972.

Mexican Maize Races

In Mexico, maize races have been classified into the following groups using agronomical criteria: Ancient Indigenous, Exotic Pre-Columbian, Mixed Prehistoric, Incipient Modern, and Poorly Defined (Wellhausen et al. 1951). In the present study we found that each group has characteristic values for the length, width, thickness, hardness, and specific gravity of the kernels. The races in the Ancient Indigenous group had the lowest weight for 1000 kernels (199 g), the highest specific gravity (1.26g/cm^3), and a hard endosperm. These races also had the lowest water absorption capacity (WAC: 1.082 l water/kg flour) and tortilla yield. This means that although these races can be used to make tortillas, they are more appropriate for snacks and popcorn. An example of this kind of vitreous maize race is Palomero Toluqueño. On the other hand, the exotic pre-Columbian races had, on average, the highest WAC (1.190 l water/kg flour) and are usually floury kernel races that are not appropriate for the nixtamalization process. The high viscosity of the starch (particularly in the case of Harinoso del Ocho, 399 Rapid Viscosity Units [RVUs]) makes them more useful as thickeners. In contrast, races like Dulce del Noroeste (in the Poorly Defined group), with 43 RVUs, can be used in *tejuino* type drinks. We found that the maize races appropriate for making tortillas had viscosities between 121 and 256 RVUs. The thermal profile of these races during ohmic cooking and DSC testing showed a clearly defined curved transition zone in contrast with races inappropriate for making tortillas, whose thermal profiles were practically a straight line.

Maize races of hard kernel texture had higher initial and final gelatinization temperatures than did soft kernel types. For example, Azul-Cristalino de Chihuahua, a race appropriate for making tortillas, has a smooth texture, a low gelatinization temperature, and good tortilla yield. On the contrary, Reventador maize, for making popcorn, is hard and has a low WAC, low tortilla yield, and high gelatinization temperatures.

Maize Races in South and Central America and the Caribbean

In order to facilitate analysis, we performed a PC analysis of grain and quality variables. Maize races from the Andean countries (Ecuador, Peru, Bolivia, and Chile) fell in the positive PC1 and negative PC2 quadrant of the Principal Component (PC) graph. These races had the highest weight of one thousand kernels (WT1000) and the largest kernels, with low kernel hardness and specific gravity (SG).

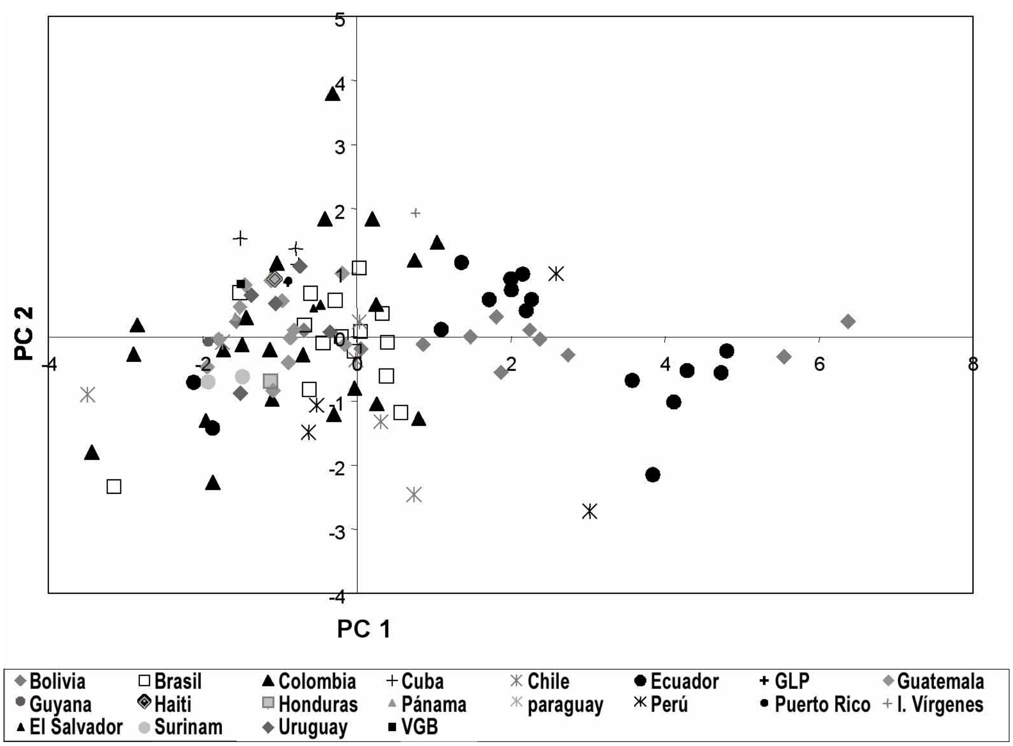
They are usually maize with floury starch (Sturtevant 1989; Goodman and Brown 1988). These maize races are mainly used to make sweet beverages like *atole* (Goodman and Bird 1977). The races with high values for kernel hardness and SG, low WT1000, and small kernels appear in the negative PC1 and positive and negative PC2 areas of the graph. They are mainly from Colombia, as well as Guatemala, Guyana, Surinam, Peru, Chile, and some from Brazil. Most races from these countries, such as the Pira, Chococeño, Canguil, Curagua, Perla, and Naltel are for making popcorn. Nevertheless, some genotypes with less kernel hardness in the endosperms can be used to make products like *arepas*, snacks, and nixtamalized tortilla flours, which are usually prepared with a hard texture kernel and can be dry milled.

Races with intermediate values for WT1000, hardness, and kernel size are found in the center of the plot (Figure 1). In this group we find races Dente Ríograndense from Brazil, Uchuquilla from Bolivia, and some Colombian races like Sabanero, Cariaco, and Puya. Races from Paraguay and Uruguay generally have hard kernels and high specific gravity, although large, soft kernels are also found. Principal Component 1 and 2 for the kernel trait variables explained 78.05% of the total variation (Table 2).

Table 2. Principal components (PC1 and PC2) for kernel traits.

Variable	PC1	PC2
1000 Kernel weight	0.488	0.287
Specific gravity	-0.416	0.402
Hardness	-0.302	0.719
Length	0.428	0.206
Width	0.426	0.435
Thickness	0.0364	0.080

Figure 1. Distribution of maize races from South and Central America and the Caribbean based on kernel traits.



In the grouping of maize races in South and Central America and the Caribbean based on the tortilla making quality traits, the most significant variables with PC1 positive were WAC, MY, and TY. The most significant variable with PC2 positive was TWL. The principal component 1 and 2 for tortilla quality variables explained 84.2% of total variation (Table 3).

Table 3. Principal components (PC1 and PC2) for tortilla making quality traits.

Variable	PC1	PC2
WAC	0.554	0.298
MY	0.551	0.301
TWL	-0.279	0.684
TY	0.502	-0.461
Cutting force	-0.244	-0.373

WAC=water absorption capacity; MY=masa yield for tortilla; TWL=tortilla weight loss during cooking; TY=tortilla yield.

Figure 2. Distribution of maize races from South and Central America and the Caribbean based on tortilla making quality characteristics.

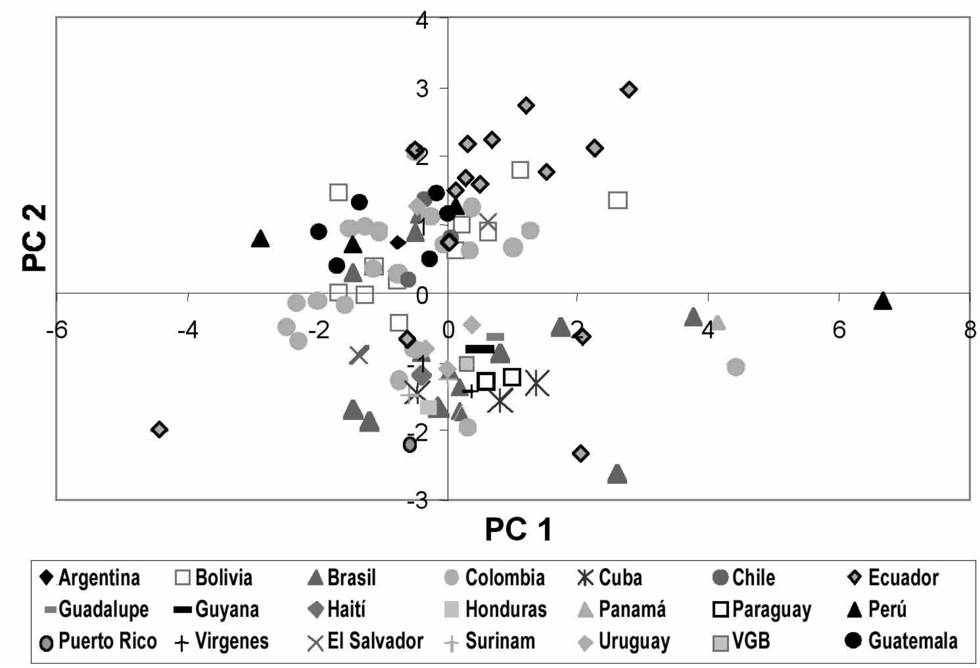


Figure 2 shows that the distribution of the different maize races reflects specific patterns that correspond to their geographical distribution. For example, the maize races with a hard endosperm and negative PC1 (low WAC, MY, and TY) are found in a specific area of the graph. These races are mainly from Colombia (Puya, Yucatán, Pira, Clavo, Montaña, Cariaco, Común, and Costeño), Peru (Cuzco Cristalino, San Jerónimo), Bolivia (Uchuquilla, Kellu, and Perla), Chile (Diente de Caballo and Camelia), and Pisingallo from Argentina. They can be dry milled or used to make products like *arepas*, snacks, and nixtamalized flours, which usually require maize with a hard endosperm. Some of these races, like Chococeño, Perla, Camelia, Curagua, Pisingallo, and Popcorn are appropriate for popcorn because of the small size of the kernel. Most of the samples from Ecuador (Pool A (Andino) 1 C6, Pool A 1 C12, Shima, Cangil, Pool A 5 C6, Pool A 4 C12, Pool A 4 C7) and from Bolivia (Hualtaco, Huillcaparu, Kellu, Kulli) are also plotted in this area but in the positive region of PC1 and PC2. These corn races are soft, with high WAC and TWL. They are floury materials appropriate for thickeners and making drinks like *atole*. In the central area of the plot, with both positive and negative PC1 and negative PC2, we find most of the samples from the Antilles: Cuba (Canilla, Cuban Flint, Cuban Yellow Flint), races from other islands such as Haiti (Haiti Yellow), Puerto Rico (Tusón), the Virgin Islands (Sacramento), VGB (Coastal Tropical Flint), and Guadalupe (Early Caribbean), as well as from Central America: Guatemala (Tepecintle), Honduras (Salvadoreño-Naltel), El Salvador (Salvadoreño-Olotón), Panama (Clavillo-Salvadoreño), and from South America: Guyana, (Cateto Nortista-Cuban Yellow Flint), Surinam (Cateto Nortista Precoz), Brazil (Dente Riograndense Liso, Dente Riograndense Rugoso, Dente Paulista), Uruguay (Cateto Sulino), and Paraguay (Avatí Morotí). Although these are yellow corns, they can be used to make traditional tortillas, because of their WAC and low TWL. The races that are closer to the negative part of PC1 have potential uses for snacks and nixtamalized flour because of their hardness. Races like Sabanero from Colombia and Pool A 7 C9, with high values for WAC and TY, appear in the negative PC2 and highly positive PC1 area (Figure 2).

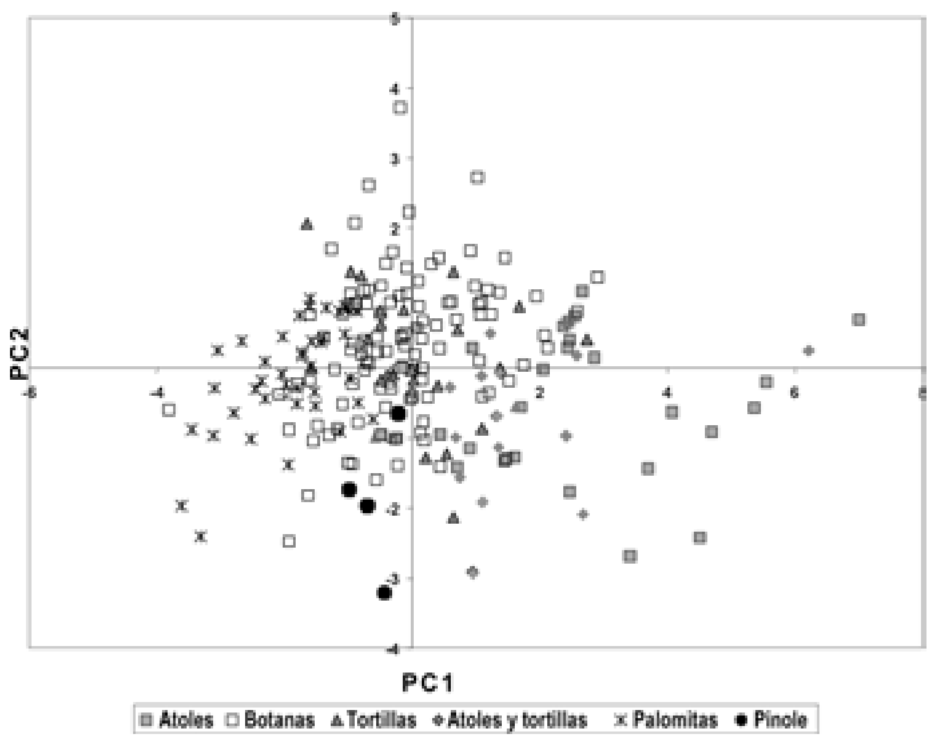
Principal component analysis for the tortilla making quality traits of all the samples was done to compare the Mexican races to those from the rest of the American continent. The first and second variables explained 82.3% of the total variation. The principal component variables are shown in Table 4, where it can be seen that the races with high values for WAC, MY, and TY are found in the positive PC1 area. These races are used for making tortillas and atoles.

Table 4. Principal components (PC1 and PC2) for tortilla making quality traits.

Variable	PC1	PC2
WAC	0.603	0.257
MY	0.603	0.254
TWL	-0.169	0.709
TY	0.453	-0.537
Cutting force	-0.196	-0.279

WAC=water absorption capacity; MY=masa yield; TWL=tortilla weight loss during cooking; TY=tortilla yield.

Figure 3. Distribution of maize races from Mexico, South and Central America, and the Caribbean based on measurements of tortilla making quality traits and potential end use. Food use predictions were calculated with weighted Euclidean distances.



The accessions with high TWL and low WAC are found near the center of the plot toward the negative portion of PC1 and the positive and negative regions for PC2. These accessions are generally appropriate for making popcorn and other snacks.

Conclusions

The traditional evaluations such as WT1000, SG, and kernel hardness gave information about the kernel texture. For example, maize races such as Azul-Cristalino de Chihuahua, Cacahuacintle, Elotes Occidentale, Azul-Bofo, Kulli, Hualtaco, and maize from the Andino Pools showed high WT1000 and hardness and low SG. The races with hard endosperm such as Palomero, Naltel, Chapalote, Reventador, Popcorn, Canguil, Pira, and Chococeño, among others, showed generally low WT1000 and high SG and hardness. The PC for kernel and tortilla quality traits for Mexican races as well as Central, South American, and Caribbean races showed similar tendencies related to the final use. The food use predictions for popcorn, tortillas, atoles were found at specific positions on the PC plot. The quality of different maize races related to WAC, TWL, and TY followed specific patterns that correspond to their geographical distribution.

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References

Arámbula V.G., S.R.A. Mauricio, J.D.C. Figueroa, J. González-Hernández, and F.C. Ondorica. 1999. Corn masa and tortillas from extruded instant corn flour containing hydrocolloids and lime. *J. Food Sci.* 64(1): 120-124.

Goodman, M. M., and R. M. Bird, 1977. The races of maize IV: tentative grouping of 129 Latin American races. *Economic Botany* 31: 201-221.

Goodman, M.N., and W.L. Brown. 1988. Races of corn. In: G.F. Sprague and J.W. Dudley (eds.), *Corn and corn improvement*. ASA Monograph 18. ASA, Madison, Wisconsin. Pp. 33-79.

Hernández, X. E. 1972. Consumo humano de maíz y el aprovechamiento de tipo con alto valor nutritivo. In: *Simposio sobre desarrollo y utilización de maíces con alto valor nutritivo*. Colegio de Posgraduados, E.N.A. Chapingo, México. Centro Médico Nacional del IMSS. México D.F. Junio 29 y 30 de 1972. pp:149-156.

Mauricio, S.R.A., J.D.C. Figueroa, S. Taba, V.L.M. Reyes, S.F.Rincón, y G.A. Mendoza 2004. Caracterización de accesiones de maíz por calidad de grano y tortilla. *Rev. Fitotec. Mex.* 27(3):213-222.

Sturtevant, E. L. 1989. Varieties of corn. *USDA Off. Exp. Stn. Bull*. 571: 1-108.

Wellhausen, E.J., L.M. Roberts, and X.E. Hernández, 1951. *Races of maize in Mexico: their origin, characteristics and distribution*. 1st. Edition. The Bussey Institution of Harvard University. Pp: 23-44.

Enhancement of Farmers' Maize Varieties with an Improved Population in Saltillo, Coahuila, Mexico

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Abstract

Livelihoods of farmers in Mexico can be improved through enhancing yield potential of local maize varieties. Two strategies for genetic enhancement are considered and being implemented in Jagüey, Saltillo, and Coahuila, Mexico. First, a good donor germplasm source was identified for its combining ability with the local varieties and introgressed into one of them. Second, on-farm improvement of the local variety is achieved by full-sib selection. Farmers and a local breeder have been involved in progeny evaluation and selection on-farm. The first enhancement cycle of Jagüey (local landrace) x CPRE (improved population) significantly increased grain yield potential on-farm over the original variety in Jagüey, Coahuila, Mexico.

Key words: Maize landrace, participatory breeding, on-farm conservation.

Introduction

In Mexico, approximately 70% of the cultivated maize area is planted with local varieties. These are usually grown under non-optimal agronomic conditions, adapted to variable rainfalls, and tolerant to biotic and abiotic stresses. These varieties (landraces) are attractive to farmers, due to their flexible response to adverse situations. They are frequently used for seed exchange among farmers, within the same community or with other communities. Several researchers have emphasized that the conservation and sustainable utilization of genetic diversity of landrace varieties is feasible under traditional agricultural systems (Dempsey 1996; Louette and Smale 1996). Participatory plant breeding has been suggested as a potential strategy to enhance local varieties while preserving the inherent genetic diversity as well as other characteristics of interest, useful in a traditional, sustainable system (Eyzaguirre and Iwanaga 1996a; Louette and Smale 1998). Moreover, the efficient use of local materials in a sustainable cropping system requires the integral and comprehensive participation of personnel with a variety of expertise (Geilfus 1998). Enhancement and improvement of local varieties for a sustainable production system can be accomplished through the joint efforts of formal breeders working with farmers in the improvement of their genetic resources within the unfavorable environments (Eyzaguirre and Iwanaga 1996b).

The objective of this study was to evaluate the agronomic performance of an adapted maize variety in Saltillo, Coahuila, Mexico, and to improve its performance under local growing conditions by crossing it with an improved maize population available through a participatory plant breeding approach.

Materials and Methods

This paper integrates two components, first, an evaluation of locally adapted varieties, and second, a study dealing with crop improvement of a local farmers variety using the participatory plant breeding scheme. The study area was located at Jagüey de Ferniza, Saltillo, Coahuila, which is located at an altitude of 2100 masl, has an average precipitation of 407 mm, and an average temperature of 20 °C during crop development.

To choose an elite germplasm donor, 10 local varieties were collected in the regions of Saltillo, Arteaga, and Parras in Coahuila in 1997. They were testcrossed with the following testers: VS-221, CAFIME, and CPRE, the latter, an experimental population formed with 13 inbred lines, selected on the basis of their combining ability and developed by the Instituto Mexicano del Maíz, Universidad Autónoma Agraria Antonio Narro (UAAAN). The testcrosses were evaluated in Celaya, Guanajuato in 1998 and 1999, under well-watered conditions, and in this paper only 1999 data are presented in Table 1 (Rincón-Sánchez et al. 2004). The evaluation data of the varieties and testcrosses included days to flowering (anthesis and silking), plant and ear heights (m), husk cover (%), stalk and root lodging (%), and grain yield (t/ha) adjusted to a 15% moisture content. Mid-parent heterosis (%) for grain yield was estimated by testcross performance and the average performance of the variety and the tester (Falconer and Mackay 1996). The general and specific combining ability effects for the entries were computed according to Hallauer and Miranda (1988).

A locally adapted maize variety named Jagüey from Jagüey de Ferniza, Coahuila, and CPRE (early maturity improved population chosen as a donor from the first experiment) were intercrossed at Tepalcingo experimental station, Morelos, Mexico, in 2000. Jagüey was considered to be a local variant of the variety Cuauhtémoc, a white grain type evaluated in the testcross trial (Table 1). The resulting 182 full-sibs were evaluated during 2001 at three sites: Celaya, Guanajuato (1800 masl) and Derramadero, Coahuila (1650 masl), both under irrigation, and at Jagüey de Ferniza, Coahuila (2100 masl), under rainfed conditions (407 mm). The best families (10%) were selected based on the evaluation data under irrigated and rainfed conditions, with special emphasis on the performance under the rainfed environment and the preference of the cooperative farmers for certain plant and ear traits at these locations. Besides the phenotypic expression, selection index was computed using husk cover, stalk and root lodging, and days to flowering (Barreto et al. 1991) and was also used for selecting the best families for recombination and formation of an enhanced local variety named Jagüey.

To evaluate the performance of the enhanced local variety Jagüey with introgression (50%) from the elite experimental population CPRE, 80 full-sib families were generated in the original local variety (Jagüey C_0), and 90 full-sib families were generated in the enhanced local variety (Jagüey x CPRE C_1). Field evaluations were carried out at Celaya, Guanajuato (1800 masl) under irrigation and Jagüey de Ferniza, Coahuila (2100 masl) under rainfed conditions. The experiments used an incomplete block design with two sets of the full-sib families and had two replications planted in a 5 m long row with 21 plants. Table 2 shows the mean performance of the families for the agronomic traits: plant and ear height, husk cover, root and shoot lodging, ears per plant, days to anthesis and silking (anthesis-silking interval, ASI), grain moisture at harvest, and grain yield.

Results and Discussion

Identification of a Donor Germplasm Source

Mean squares for grain yield of the local varieties in crosses with three testers or potential germplasm donor sources for enhancing the local varieties showed significant differences among varieties ($P \leq 0.01$) and testers ($P \leq 0.05$), indicating the levels of genetic variation among the farmer varieties and testers (data not shown). The yield of the local varieties varied from 1.6 to 10.3 t/ha. Heterosis and combining ability estimates indicated that local varieties could be discriminated by the use of a particular tester (Table 1). Considering the average performance of local varieties, as well as their specific combination with testers, CPRE made a highly significant contribution to additive genetic effects (0.358*) with an average heterosis value of –10.7 with 10 local varieties. It also had the highest yield of 13.5 t/ha. The results suggest that the elite experimental population (CPRE) can be used as a donor source to enhance the local varieties in the regions of Coahuila, Mexico. It seems that a participatory plant-breeding program with the aim of enhancing local maize varieties will require a preliminary genetic study to determine which local variety will be enhanced by which donor source.

Table 1. Means for grain yield of ten local varieties and estimates of mid-parent heterosis and general and specific combining abilities (GCA, SCA) in crosses with the three testers in Celaya, Guanajuato, Mexico, 1999.

	Yield			Mid-parent heterosis(%)†			SCA				
Entries	t/ha	GCA		VS221	CAFIME	CPRE	VS221	CAFIME		CPRE	
Local varieties											
Chapultepec	4.296	-2.101	**	22.7	-13.4	-24.0	-0.363	1.256	*	-0.892	
Santa Fe	7.522	0.109		22.8	1.1	-13.0	0.267	-0.667		0.399	
Cuauhtémoc (Mixture)	6.595	1.373	**	48.6	3.0	13.9	0.150	-1.340	*	1.190	*
Cuauhtémoc (White)	7.379	0.968	*	35.1	11.7	-20.1	0.409	0.020		-0.429	
Garambullo (White)	7.767	-0.212		11.7	-9.3	-7.9	-0.173	-0.543		0.717	
Garambullo (Mixture)	5.025	0.371		49.6	44.7	-0.4	-0.735	0.670		0.065	
Sabanilla	10.253	1.968	**	25.5	13.6	-5.0	-0.260	-0.477		0.717	
San José	5.715	-1.459	**	0.8	-14.8	-42.4	0.817	0.549		-1.366	*
Pinto mosca	1.639	-0.984	*	81.2	66.5	-4.9	0.630	-0.256		-0.374	
Galeana	6.234	-0.033		21.8	23.3	-3.3	-0.741	0.788		-0.047	
Mean	6.243			32.0	12.6	-10.7					
Testers											
VS221	7.534	0.219									
CAFIME	7.783	-0.576	**								
CPRE	13.515	0.358	*								

† Computed based on the difference between the mid-parent and the testcross families performance;
*, ** Significantly different at 0.05 y 0.01 probability levels, respectively; data adapted from Rincón-Sánchez et al. (2004).

Performance of the Enhanced Local Variety

Table 2 shows the agronomic performance of the original local variety, Jagüey C_0, represented by 80 full-sib families and the enhanced variety Jagüey x CPRE C_1, represented by 90 full-sib families. Grain yield of Jagüey x CPRE C_1 increased 43.7% and 25.6% over Jagüey C_0 for trials at Celaya, Guanajuato and Jagüey, Coahuila, Mexico, respectively. Other traits such as a reduction of stalk and root lodging, ASI, and husk cover are also noted in the enhanced Jagüey x CPRE C_1 under the rainfed growing conditions at Jagüey, Coahuila, Mexico. The results indicated that finding a good donor source that combines well with the local variety could be a way of improving it, even under rainfed conditions. From the evaluation trials, a set of 10% of families was selected for another cycle of full-sib selection in both breeding populations.

Table 2. Mean performance of 80 full-sib families of the local variety Jagüey C_0 and 90 full-sib families of the enhanced variety with CPRE Jagüey x CPRE C_1 in Celaya, Guanajuato, and Jagüey, Coahuila, Mexico, 2002.

	Celaya, Guanajuato†					Jagüey, Coahuila. ‡				
	Jagüey C_0		Jagüey x CPRE C_1			Jagüey C_0		Jagüey x CPRE C_1		
Traits	mean	se¶	mean	se	dif. (%)	mean	se	mean	se	dif. (%)
Plant height (cm)	265	2.09	251	1.35	-5.41	179	3.11	187	2.16	4.79
Ear height (cm)	155	1.85	144	1.38	-6.73	102	2.67	109	1.89	6.17
Husk cover (%)	30.4	1.49	38.1	1.61	25.47	5.6	1.13	4.6	0.41	-18.39
Root lodging (%)	28.0	2.13	21.5	1.11	-23.17	7.1	1.19	5.1	0.89	-27.64
Stalk lodging (%)	8.3	0.95	2.9	0.41	-64.96	13.8	2.15	11.0	1.13	-20.15
Prolificacy	1.0	0.02	1.2	0.01	17.06	0.9	0.02	1.1	0.02	11.30
Days to anthesis	66	0.24	65	0.19	-1.45	82	0.64	83.5	0.41	1.82
Days to silking	69	0.24	67	0.21	-1.60	85	0.66	86.4	0.48	1.94
ASI	2.4	0.12	2.3	0.08	-5.61	3.2	0.26	3.0	0.18	-5.52
Yield (t/ha)	6.196	0.19	8.903	0.12	43.68	5.121	0.26	6.431	0.13	25.57

† irrigated conditions; ‡ rainfed conditions; ¶ se = standard error; ASI = anthesis-silking interval.

Participatory Local Maize Improvement

A participatory approach to local maize improvement involving farmers and local breeders (Rincón-Sánchez et al. 2002ab, 2004) uses a combination of local and improved germplasm in a recurrent selection scheme. The farmers in Ejido Jagüey de Ferniza have provided land to set up the experiments, contributed their local germplasm, and cooperated directly during the crop season, including evaluation of and selection among the full-sib families at harvest. A plant breeder's contribution consisted of developing breeding crosses at an experimental station. One of the potential in situ conservation strategies in Mexico is the use of a half–sib family selection scheme. A pilot experiment was established at Jagüey de Ferniza, Coahuila during 2002, using selected ears of a local variety planted as a composite. Before flowering, alternate male and female rows were designated in the field, and all female rows were detasseled to avoid selfing. At harvest, ears were selected from both male and female rows and were kept separately. A mixture of the male ears makes up the traditional mass selection developed by farmers, whereas the female ears are half-sibs to be used for evaluation and selection in the next improvement cycle on-farm, as well as for planting for grain production. The results of the latter experiments with the farmers will be evaluated in the future.

References

Barreto, H. J., J. A. Bolaños, and H. S. Córdova. 1991. Programa Índice de Selección. Guía para la operación del software. Mexico, D.F.: CIMMYT. pp. 27.

Dempsey, G. J. 1996. *In situ conservation of crops and their relatives: A review of current status and prospects for wheat and maize*. NRG Paper 96-08. Mexico, D.F.: CIMMYT. pp. 33.

Eyzaguirre, P., and M. Iwanaga (eds.). 1996a. *Participatory plant breeding. Proceedings of a workshop on participatory plant breeding.* 26-29 July 1995. Wageningen, The Netherlands. IPGRI, Rome, Italy. pp. 164.

Eyzaguirre, P., and M. Iwanaga. 1996b. Farmer's contribution to maintaining genetic diversity in crops, and its role within the total genetic resources system. In Eyzaguirre, P. and M. Iwanaga (eds.), *Participatory plant breeding. Proceedings of a workshop on participatory plant breeding*. 26-29 July 1995. Wageningen, The Netherlands. IPGRI, Rome, Italy. pp: 9-18.

Falconer, D. S., and T. F. C. Mackay. 1996. *Introduction to quantitative genetics*. Fourth edition. Longman Group Ltd. England. pp. 464.

Geilfus, F. 1998. *80 herramientas para el desarrollo participativo: diagnóstico, planificación, monitoreo, evaluación*. IICA-GTZ, San Salvador, El Salvador. pp. 208.

Hallauer, A. R., and J. B. Miranda. 1988. *Quantitative genetics in maize breeding*. Second edition. Iowa State University Press. Ames. USA. pp. 468.

Louette, D., and M. Smale. 1996. *Genetic diversity and maize seed management in a traditional Mexican community: Implications for in situ conservation of maize.* NRG Paper. 96-03. Mexico, D.F.: CIMMYT. pp. 22 .

Louette, D., and M. Smale. 1998. Farmer's seed selection practices and maize variety characteristics in a traditionally-based Mexican community. CIMMYT Economics working paper No. 98-04. Mexico, D.F.: CIMMYT. pp. 33.

Rincón-Sánchez, F., N. A. Ruiz-Torres, and H.De León-Castillo. 2002a. *Genetic Potential of Locally Adapted Maize Populations and Participatory Crop Improvement for Rainfall Environments.* ASA-CSSA-SSSA Annual Meeting Abstracts, November 10-14, Indianapolis, IN., USA.

Rincón-Sánchez, F., H. De León C., N. A. Ruiz T. y J. L. Herrera A. 2002b. *Avances en el aprovechamiento de germoplasma de maíz bajo el enfoque del mejoramiento participativo*. Simposio. Manejo de la Diversidad Cultivada en los Agroecosistemas Tradicionales. 13 al 16 de febrero del 2002. Mérida, Yuc. México. pp. 54-55.

Rincón-Sánchez F., N. A. Ruiz-Torres, H. De León-Castillo, and J. L. Herrera-Ayala. 2004. Advances on the use of maize germplasm under the participatory plant breeding approach. In J. L. Chávez-Servia, J. Tuxill, D. I. Jarvis (eds*), Manejo de la diversidad de los cultivos en los agroecosistemas tradicionales.* Instituto Internacional de Recursos Fitogenéticos, Cali, Colombia. pp. 177-186.

Country Reports

Argentina

Marcelo E. Ferrer

The active germplasm bank in the Instituto Nacional de Tecnología Agropecuaria (INTA) in Pergamino conserves more than 2,500 maize accessions. The bank has assembled 2,350 accessions of maize landraces from various collection missions (1951, 1963, 1965, 1968, 1977, and 1994). These accessions were collected from the Pampeanean region as well as the northeastern region, which includes the Andean provinces of Salta, Catamarca, and Jujuy. The accessions were collected from an area that covers an altitude range from sea level to 3,500 masl. This germplasm has been classified into 44 racial groups. Commercial hybrids, which are largely grown in the Pama region, have replaced the local landraces. A sample of the active collection is duplicated and stored in the base collection. In 1984 and 1987, INTA sent the National Seed Storage laboratory (NSSL) at Fort Collins, Colorado, USA (now National Center for Genetic Resources Preservation, NCGRP) 1,624 accessions as duplicate samples that were collected in 1977 and 1986 in collaboration with the International Board for Plant Genetic Resources (IBPGR) (now International Plant Genetic Resources Institute, IPGRI). From 1998 to 2002, 578 accessions were regenerated at Pergamino. In 2000, 287 accessions were sent to CIMMYT for regeneration. CIMMYT has regenerated most of them and has returned them to INTA's active bank. The same accessions were duplicated at CIMMYT and NCGRP in 2003. Priority for regeneration is highest for the high altitude collections from the northeastern region.

There are two active seed bank storage rooms, each of which is 13m^3 in size. The room temperature is set at 7^{o}C. These rooms are used for storing maize, forage, and sunflower collections. Another cold room is available at -20^{o}C for long-term seed storage, which can hold 15,000 1kg samples. By 2002 a total of 2,332 accessions were dried to 6% seed moisture. It takes 25-30 days to dry to this extent in the current dryer, operating at 20^{o}C and 15% relative humidity (RH). The seed samples are stored in aluminum foil bags.

Passport and characterization data of the accessions are complete. There are evaluation data on protein, oil, and starch (conducted in 1990 for some of the accessions). All data has been listed in the CIMMYT catalog published in 1998. In addition, Argentina evaluated 334 accessions as part of the Latin American Maize Project (LAMP). In 2000, in collaboration with the breeders, some 250 elite accessions of the races adapted at Pergamino were testcrossed with elite lines to evaluate combining ability and value-added traits. The best breeding crosses (10%) were backcrossed with elite lines. In 2002, 21 breeding crosses were identified as the best breeding sources. Argentina has supported a multilateral exchange of germplasm and signed the International Treaty (IT) for plant genetic resources.

Bolivia

Gonzalo Ávila and Lorena Guzmán V.

In 1998, the Centro de Investigaciónes de Fitoecogeneticos de Pairumani (CIFP) published a catalog of Bolivia's maize germplasm accessions. It included passport and characterization data for 1,448 landrace accessions and 7 racial composites. A total of 463 accessions have been duplicated through the regeneration project at CIMMYT and NCGRP and are identified by a BOZM prefix. NCGRP preserves duplicated samples that had been sent before the current landrace regeneration project.

In 2002, the active bank was constructed at CIFP, Cochabamba, Bolivia. It has 190m^3 capacity and is maintained at 0^{o}C with 55% RH. The seed moisture is 10% with an expected seed viability of 10-15 years. The sample size is 2-5kg, stored in a plastic container. From 1993 to 2000, CIFP sent 576 accessions, regenerated by the cooperative regeneration project, to CIMMYT and 505 accessions to NSSL. An additional 22 accessions were regenerated at CIFP in cooperation with the Instituto Nacional de Investigaciones Agropecuarias (INIA), Chile. It is obligatory to have a germplasm access contract with collaborators for germplasm exchange, under article 391 of the Andean Pact.

Under the LAMP, 500 Bolivian accessions were evaluated. Since then, accession evaluation has continued and passport and characterization data have been published in the catalog. A core collection has been identified using the available data. Races Hualtaco and Huilcaparu have been evaluated in farmers' fields predominantly in the Cochabamba valley. These races are known to be drought tolerant and farmers prefer their grain types. CIFP's first year racial accessions and new collections from the cooperating farmers in the valley were grown in farmers' fields, and the best 20% entries were selected using a participatory approach with the farmers. The original seed accessions of the best 20% and the balanced seed bulk of them as the male parent were planted in half-sib recombination plots in both the farmers' plots and in Pairumani. The seed lot was mixed from both recombination plots and constituted improved basic seed for the farmers to grow in the third year. The improved seed of the land races should help the farmers to cultivate them, thus maintaining maize germplasm on-farm in situ.

Brazil

Flavia Franca Teixeira and Ramiro Vilela de Andrade

The active germplasm bank at the Centro Nacional de Pesquisa de Milho e Sorgo (EMBRAPA) conserves 3,886 maize accessions. The collection consists of landraces (82%), composites (5%), improved germplasm (6%), and introductions from other countries (7%). Current core accessions, of which there are about 353, are designated according to geographical adaptation and grain type. Further refinement of the core collection will be carried out. The seed is stored at 5-6^{o}C with RH of 25-30%. Regeneration is initiated when the seed germination is below 80%. Germination of the collection has been monitored every five years. Every year, some 250 accessions are regenerated, with 100 ears that represent the accession. There are three regeneration sites: Sete lagoas (wet sub tropical/tropical climate, Mato Grosso [MG]), Janauba (dry sub tropical climate, Minas Gerais), and Londrina (southern temperate region in Parana [PR]). The seed exchange policies have to meet the regulations of the National Genetic Resources Council.

The core collection is actively evaluated for phosphorous use efficiency, aluminum tolerance, biotic stresses, and combining ability. Husk quality is also evaluated for those farmers' communities who use maize husks for manufacturing dolls, purses, baskets, etc. Prebreeding, using data from LAMP and GEM (germplasm enhancement of maize in the USA), has used the core collection for crossing with elite germplasm lines. Working with the Krahos Indian tribe, five races of maize from Xavantes have been returned to in situ collection sites, to preserve them within the local culture.

Chile

Gabriel Saavedra Del Real

In 1999, the Instituto Nacional de Investgaciónes Agropecuarias (INIA) created a maize breeding program to develop commercial hybrids of Choclero (green ear corn of the race Choclero). Since 1964, INIA's maize breeders have been working on development of varieties and hybrids. After 1990, private companies increased the development of hybrids of flint and dent grain types, and in the late 1990s INIA reduced their maize breeding research. Currently, 1,247 accessions are preserved in the active collection, including breeding lines recently added to the original collection. Landrace collections in Chile were assembled in 1953-1955 and 1981-82 (536 accessions). Chile's catalog of maize accessions was published in 1990. At La Platina experimental station an inventory is being gathered of the active collections that had been managed by the previous maize program. Data on seed amounts and viability are being updated. Active use of landrace germplasm, to increase genetic diversity for breeding Choclero grown extensively in Chile, is expected.

Colombia

Alejandro A. Navas Arboleda

Since 1994, the Corporación Colombiana de Investigación Agropecuaria (CORPOICA), with the support of the Ministry of Agriculture and Rural Development, has been responsible for the national germplasm bank. In total, 4,200 accessions are preserved at the bank; 2,200 accessions originate from Colombia, and others are of foreign origin. There are 3,405 registered accessions with more than 1,500 seed samples and documentation of passport data. Seed samples have been dried to 10% seed moisture and stored at -20^{o}C for the base collection and 0^{o}C for the active collection. The seeds are packed in aluminum foil bags. The active collection preserves 2,657 accessions. Seed viability has been tested and maintained at over 85% in the base collection. However, there is a need for the accessions to be regenerated. Characterization has advanced little and there is a need to capture passport information and seed inventories in a bank database. A total of 203 accessions have been evaluated for agronomic traits, in addition to data obtained from LAMP. Seed exchange will need authorization from the Ministry of Agriculture and Rural Development and perhaps other authorities (the Ministry of Environment and Instituto Colombian de Agricultura, ICA).

Ecuador

Carlos Yanez, José L. Zambrano, Marlon Caicedo, and Jorge Heredia

Instituto Nacional de Investigaciones Agropecuarias (INIAP) has a Department of Agrobiodiversity where the maize bank collection is stored. It has 1,056 accessions, of which 961 accessions originate from the highlands (higher than 2,200 masl). The base collection is stored at -15^{o}C and 5-6% seed moisture. The active bank maintains the seed samples at 5^{o}C with 14% seed moisture and needs periodic seed regeneration every 5 years. Seed samples in the base collection are dried at 20^{o}C with 15% RH. The base bank uses the PCGRIN database program, whereas the Excel program is used to manage the seed inventories for the active collection. Characterization of the accessions is one of the components of the project called integral management of maize genetic resources, supported by PROMSA (Programa de Modernización del Sector Agrícola). Seven hundred and fourteen accessions have been characterized using agro-morphological traits and 220 accessions by molecular characterization using microsatellite and RAPD techniques. Using these data, core subsets will be designated in the near future.

Ecuador has 27 maize races, of which 17 are found in the highlands. From 1993, participatory breeding of the local races with the farmers in the provinces of Imbabura, Bolívar, Chimborazo, Cotopaxi, Tunguraguhua, and Pichincha resulted in development of the improved varieties: INIAP 122 (yellow floury, race Huandango type); INIAP 111 (white floury, race Guagal type); INIAP124 (yellow floury, race Mishca type); and INIAP 102 (white floury, race Blanco Blandito). The farmers were involved in the agronomic and culinary selection of germplasm accessions to advance selection and recombination to develop the improved varieties. Women farmers were involved in the culinary selection (choclo, green ears), whereas men were mainly responsible for selection of germplasm with desirable agronomic traits.

Guatemala

Mario Roberto Fuentes López

In 2003, Instituto de Ciencia y Tecnología Agropecuaria (ICTA) constructed an active germplasm bank storage facility, located at 1,450 masl, in Guatemala City. In 2002, the maize program collected 73 new accessions from the northern highland regions of Los Cuchumatanes and Huehuetenango and 113 accessions from arid lowland regions. These accessions were stored in the new active bank. Seed moisture of the accessions is about 7% and seeds are stored at 10-15^{o}C in a crystal jar containing 0.5-1 kg seeds per accession. The Ministry of Agriculture regulates seed exchange, and ICTA oversees it through contracts and collection projects. ICTA maintains a list of the germplasm collected and exchanged with collaborators. Characterization of these new accessions, collected in both highlands and lowlands, is planned for 2003-2005.

In the northern highlands, the teosinte race should be preserved in situ. Evaluations of accessions on-farm are planned with the farmers in the regions. In

2003-2005, participatory variety selection will be conducted to choose the best accessions for enhancement of local races. Teosinte found in the lowlands should be collected and preserved in the active bank. Early maturing maize races in the arid zones will be collected and evaluated on-farm. ICTA plans to regenerate all new accessions as well as some of the accessions held at CIMMYT for further characterization on-farm in situ.

Mexico

Juan Manuel Hernández Casillas

The number of registered accessions at the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) maize bank is 9,881, of which 8,884 are duplicated in the CIMMYT maize bank. There are 802 accessions that will be added to the bank from new collection missions. There have been no changes to the seed storage facility in Chapingo, Mexico. The base collection is stored at 0-5^{o}C, using hermetic glass bottles and aluminum foil bags. Part of the maize collection is also preserved at Calera, Zacatecas where INIFAP's long-term seed storage facility for all crops is located. An active collection at Chapingo is maintained in three seed warehouses without temperature control. Improvement of seed storage conditions is being sought.

Annual regeneration of the accessions is being done at Iguala, Guerrero; Celaya, Guanajuato; and Chapingo, Mexico. Characterization and regeneration data is stored in electronic form to facilitate data handling and to enable efficient decision making concerns, such as which accessions need to be planted the next cycle for regeneration at those locations. The accessions that have been regenerated by the cooperative regeneration project maintain desirable seed viability, but those that still need to be regenerated have low seed viability. There is a need to restart regeneration of these accessions to restore seed viability. Additional funds will be sought for regeneration.

In the Valle Experimental Station at Chapingo, Mexico, prebreeding efforts focus on grain yield, early maturity, heterotic patterns, yellow maize, purple and red colored maize, the race Cacahuacintle, and forage maize. In the Bajío, Oaxaca, Chihuahua, and Nayarit regions, selection and use of local maize accessions are carried out with the farmers.

Paraguay

Orlando J. Noldín, Verónica Machado, and Pastor Kawamura

Centro Regional de Investigación Agrícola (CRIA), Capitán Miranda, Itapúa, Paraguay conserves 583 landrace accessions, mainly collected in 1998 and some during 1950-1987. Seed germination is expected to be low since storage conditions have not been improved. Currently, a new seed storage room is being constructed with the partial support of the project. Periodic regenerations were done in 1998-2000. There are 95 accessions, collected in 1998, which have not been duplicated at CIMMYT or NCGRP, and regeneration of these accessions has priority. In total, CIMMYT conserves 380 accessions and NCGRP conserves 378 accessions from Paraguay. It is suggested that a new inventory should be made, as the new storage room has been in operation since 2003.

In 1999, a total of 169 accessions of the Avati Morotí race were evaluated for agronomic performance at two locations (Capitán Miranda and Choré) in a 13 x 13 simple lattice design. The best twelve accessions were chosen for further evaluation on their combining abilities, and they are being used for enhancing the race using full-sib recurrent selection. In 2003, the second cycle of recurrent selection was completed. Diallel crosses among the best 10 accessions were also performed and evaluated at two locations in 2000. PAZM 01053 and PAZM 01072, collected in the Department of Concepción, demonstrated high general combining ability. Intra-racial genetic variations of the Avati Morotí race seemed significant enough to allow further improvement of the race. The study will be published. Other accessions of the Avati Morotí and Sapé Pytá races were not included in the first evaluation activity. Core subsets of the race Avati Morotí can be formed using the evaluation data from the two locations. Wilfredo Saluhuana and Verónica Machado (1999) summarized races of maize in Paraguay based on new collections in 1998.

Reference

Saluhuana, W., and V. Machado. 1999. Races of maize in Paraguay. Consideration in organization and utilization of maize genetic resources. USDA, ARS and The Maize Research Program of the Paraguayan Ministry of Agriculture and Livestock Publication 025.

Peru

Ricardo Sevilla and Julián Chura

Programa Cooperativa de Investigaciones de Maíz (PCIM), Universidad Nacional Agraria La Molina (UNALM), Lima, Peru, conserves 3,023 accessions, of which 1,442 are viable in the active collection. It collected 3,931 samples in the country during the 1950s and later again in the 1970s and 1980s. It has duplicated 1,886 accessions at NCGRP since 1985 and 934 accessions at CIMMYT since 1992. The active collection is maintained at 10^{o}C with varying relative humidity. Seed samples are placed in 1-liter glass containers and hermetically sealed. There are also other large containers, which hold more seed samples for distribution. Seed samples are dried to 8% seed moisture in forced heated airflow, since ambient relative humidity can be very high in Lima at the time of the maize harvest in the highlands. Seed regeneration is impaired by lack of adaptation of some accessions at the regeneration sites. Sixteen races: Tumbesino, Mochero, Pagaladroga, Alazán, Coruca, Confite Puneno, Arequipeño, Morocho Cajabambino, Capio, Morado Canteño, Amarillo Huancabamba, Huarmaca, Blanco Ayabaca, Huanuqueño, Enano, and Chimulos, are specifically adapted to the collection sites. They are from the coastal lowlands, southern highlands, and northern highlands. Enano and Chimulos are from the tropical lowlands and highland forest zones, respectively, and are the most difficult to regenerate. Some accessions, regenerated before 1989, require another cycle of regeneration since the seed viability is now low.

PCIM has made 50 racial composites of 3 coastal and 47 highland races. These racial composites can be enhanced by selection on-farm. Some of them have demonstrated higher yield performance than the individual accessions.

USA

Mark J. Millard

North Central Plant Introduction Station (NCRPIS), Iowa State University, Ames, Iowa had 18,057 accessions in an active maize germplasm collection in 2002. About 65% of the collection is available to the users. In the same year, more than 4,000 germination tests were performed, and 461 accessions were seed increased or regenerated to add them to the available collection. The bank distributed 4,006 samples to domestic (3,932 samples) and foreign (377 samples) users. The bank scanned and copied the NAS-NRS races of maize bulletins into Adobe Acrobat PDF format to allow future release of the information on CD-ROM and the National Academy of Science website. The goal of the project is to make information available on the original diversity of maize and to conserve the germplasm for current use and for future generations. Mark Millard, Candice Gardner, Wilfredo Salhuana, and Henry Shands have coordinated the project. The CD-ROM will be available in the near future. In 2003, some of the GEM enhanced germplasm will be deposited at NCRPIS and made available for general seed requests. CIMMYT and NCRPIS continue to collaborate with other partners in the regeneration of Latin American maize germplasm accessions. NCRPIS has imported excess seeds of the accessions that CIMMYT has regenerated. It conducts other projects on disease resistance screening, evaluation on popping expansion traits of popcorn germplasm, storing ear images, and data loading into GRIN.

Venezuela

Víctor Segovia, Francia Fuenmayor, and Yanely Alfaro

Instituto Nacional de Investigaciones Agrícolas-Centro Nacional de Investigaciones Agropecuarias (INIA-CENIAP) conserves 1,164 maize germplasm accessions, mostly originating from Venezuela, in a new seed storage room. About 50% of the accessions maintain more than 95% germination rates. Some 25% of the accessions may have seed viability as low as 50%. Currently, 40 accessions are regenerated each year. In 1998-2003, we regenerated and characterized 124 accessions. In 2002, the genetic resources unit screened bank accessions for starch, protein, and oil contents. Starch contents of 53-59% were observed, a protein content of 12-14%, and oil contents of 3-5%. Neutral fiber content of the same accessions varied between 24% and 35% in the grain.

The passport database was used to map collection sites of the accessions using GIS. Víctor Segovia intends to prepare a monograph on the Venezuelan maize collections, which will include GIS information. Working with small farmers cultivating race Cariaco, in situ conservation work was initiated in 2000.

In 2001-2002, molecular characterization using RAPD technology was performed on 11 accessions of maize races and 3 accessions that are not race-classified. These maize races were Tuson, Chandelle, Tuxpeño, Negrito, Guaribero, Canilla, Pira, Cariaco, Araguito, Cuba Yellow Flint, and Chirimito. Other accessions were Venezuela M-9 (collected in the state of Amazonas), and M413 and M403 (collected in the state of Sucre). Using 34 marker loci, these accessions were separated into 5 groups by a UPGMA-generated dendrogram (not shown). Race Pira is separated from the others. Tuson and Tuxpeño are grouped together in one category. The third group included Guaribero, Canilla, M413, Negrito, M403, Chandele, and Chirimito. The fourth group included M-9, and the fifth group included Cariaco, Araguito, and Cuba Yellow Flint. These results show the range of genetic diversity available among Venezuelan maize races.

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Acronyms and Abbreviations

AN – days to anthesis
BC_1 – enhanced populations
CESICH – INIFAP's experimental station in the state of Chihuahua
CGIAR – Consultative Group on International Agricultural Research
CIDA – Canadian International Development Agency
CIFP – Centro de Investigaciónes de Fitoecogeneticos de Pairumani, Bolivia
CIMMYT – International Maize and Wheat Improvement Center

CONASUPO – National Basic Commodities Company, Mexico

CORPOICA – Corporación Colombiana de Investigación Agropecuaria, Columbia
CPRE – Early maturity composite variety
CRIA – Centro Regional de Investigación Agricola, Paraguay
ΔH – enthalpy
DSC – Differential Scanning Calorimeter
EC – European Commission
ED – ear diameter (cm)

EH – ear height (cm)
EL – ear length (cm)
EMBRAPA – Ministério da Agricultura, Pecuária e Abastecimento, Brazil
EP – ears per plant
ER – ear rot %

EW – kernel width (cm)
FAO – Food and Agriculture Organization of the United Nations
G x E – Genotype by Environment
GCA – general combining ability
GEM – Germplasm Enhancement of Maize
GIS – Geographic Information System
GRIN – Germplasm Resources Information Network
ICA – Instituto Colombian de Agricultura, Columbia
ICTA - Instituto de Ciencia y Tecnologia Agropecuaria, Guatemala
INEGI – Instituto Nacional de Estadistica, Geographia y Informatica, Mexico
INIA – Instituto Nacional de Investgaciónes Agropecuarias, Chile
INIA-CENIAP – Instituto Nacional de Investigaciónes Agrícolas-Centro Nacional de Investigaciónes Agropecuarias, Venezuela
INIAP – Instituto Nacional de Investigaciónes Agropecuarias, Ecuador
INIFAP – National Institute for Forestry, Agriculture, and Livestock Research, Mexico
INTA – Instituto Nacional de Tecnología Agropecuaria, Argentina
IPGRI – International Plant Genetic Resources Institute (formerly IBPGR)
KL – kernel length (cm)
KRN – kernel row number

LAMP – Latin American Maize Project
LS – leaf senescence
MO – seed moisture %
MOU – memorandums of understanding
MY – masa yield
MZBANK – CIMMYT's maize database

NAS-NRC – National Academy of Sciences and National Research Council
NCGRP – National Center for Genetic Resources Preservation (formerly NSSL)
NCRPIS – North Central Plant Introduction Station, USA

OEE – Office of Special Studies, Mexico
PC – Principal component analysis
PCIM – Programa Cooperativa de Investigaciónes de Maíz, Peru
PH – plant height (cm)
PI – Principal investigators
PROMSA – Programa de Modernizacíon del Sector Agrícola, Ecuador
RG – root lodging
RH – Relative humidity
RVA – Rapid Visco Analyzer
RVUs - Rapid Viscosity Units
SAGARPA – Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación
SCA – specific combining ability
SG – shoot lodging or standability
SG – specific gravity
SH – shelling %
SI – days to silking
Tf – final temperature
TI – tillers per plant
To – onset temperature
Tp – peak temperature
TWL – tortilla weight loss during cooking

TY – tortilla yield
UAAAN - Universidad Autónoma Agraria Antonio Narro, Mexico

UNALM – Universidad Nacional Agraria La Molina, Peru
USAID – United States Aid for International Development

USDA – United States Department of Agriculture
WAC – water absorption capacity
WT1000 – weight of one thousand kernels
Y – yield