Development and Spread of Improved Maize Varieties and Hybrids in Developing Countries

Agency for International Development

ABSTRACT

Maize is the third most important cereal crop in the developing world, after rice and wheat. Attempts have been made over many years to improve maize varieties and hybrids used in developing countries. National and international programs have been involved. In the latter case, research has been concentrated at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico and the International Institute of Tropical Agriculture (IITA) in Nigeria. Both centers carry out their work in collaboration with national research programs.

Although the adoption of high-yielding wheat varieties developed by CIMMYT and of rice varieties developed by other centers has been well documented, the same is not true of maize. Part of the reason is that the genetics of maize are quite different from, and much more complicated than, wheat or rice. Improved varieties are not as easily identified visually. Also, relatively little effort has been put into the measurement process. As a result, it is not well known how much impact the maize research programs have had at the farm level.

This report is a first step in rectifying this information gap. It attempts to identify the maize varieties, hybrids, population, pools, and lines developed by CIMMYT and IITA that are being used in national programs in developing nations. It also incorporates, where available, estimates of area planted with hybrids and improved varieties. Further work is needed to more fully document the main gene pools and to verify and expand the statistical data at the national level.

Key Words

Maize, corn, maize/corn breeding, maize/corn varieties and hybrids, agricultural research, international agricultural research centers, developing countries

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DEVELOPMENT AND SPREAD OF IMPROVED MAIZE VARIETIES AND HYBRIDS IN DEVELOPING COUNTRIES

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Foreword

This report had its origins in late 1983. At that time, the Consultative Group on International Agricultural Research (CGIAR) organized an Impact Study of the research it had sponsored in developing nations. As part of the commodity portion of that effort, there was interest in initiating a study on the development and adoption of improved maize germplasm.

There was good reason for this interest. Maize is a major crop in developing countries, and it represents a major line of activity at two centers sponsored by the CGIAR—the International Maize and Wheat Improvement Center (CIMMYT) in Mexico and the International Institute for Tropical Agriculture (IITA) in Nigeria. While research on maize has been underway at both centers since their inception, relatively little has been done to trace the adoption and use of maize technology produced by these centers in cooperation with national programs.

The Agency for International Development was requested to provide some in-kind assistance to the CGIAR Impact Study. I was asked to update my earlier studies on the development and spread of high-yielding varieties of wheat and rice (Dalrymple 1986*a,b*) and some thought was given to having me initiate a similar effort on maize. The latter step, it quickly became apparent, was not possible—both because of time constraints and the need for technical knowledge of maize genetics and breeding. Hence, it was decided to contract the maize portion to a maize specialist. Dr. Nyle C. Brady, A.I.D.'s Senior Assistant Administrator for Science and Technology, was keenly interested in initiating the work and saw to it that the necessary financial resources were available for the study. The Office of International Cooperation and Development of the U.S. Department of Agriculture assisted in the search and engagement of suitable individuals to carry out the work.

Arrangements were made with Drs. David Timothy and Paul Harvey of North Carolina State University in the spring of 1984 to initiate the work. They produced a first draft by early 1986 (Dr. Timothy was primarily responsible for chapters 1 and 2 and Dr. Harvey for chapter 3). The manuscript was then distributed for technical review. In the course of this process, a considerable amount of new country information became available, principally from CIMMYT, but also from IITA and the CGIAR Impact Study itself. Unfortunately, by then, the authors had used up the time they had available for the project.

Christopher Dowswell, formerly head of the CIMMYT information office and now a consultant in agricultural communications, was subsequently engaged to incorporate this new information. He started work in early 1987 and acquired additional information from CIMMYT and IITA personnel and from national maize researchers in several Asian and African countries in the course of travels to those nations on other assignments. He also interacted with Drs. Timothy and Harvey. The revised manuscript was then reviewed again and further modifications were made; this process was completed by June 1988.

Thus, the final report is the product of a two-stage process stretching over 4 years. I think that the two stages—involving individuals with different backgrounds—introduced some "hybrid vigor" into the report. This vigor has been needed because of the pioneering and difficult nature of the enterprise. We now better understand why it has not been done before. At the same time, we recognize the importance of the task and the need to record some of the information before it disappears.

There is, inevitably, some unevenness in the country coverage in the report. Principal emphasis is placed on the distribution and use of germplasm provided by CIMMYT and IITA. Obviously, the related contributions of national programs would be given further attention in a more comprehensive treatment. More is also said about public rather than private research efforts. This is because most maize research in developing countries has been conducted by public-sector organizations and because less information is available from private-sector organizations on the genetic resources used in genotype development. Areas where the private sector is particularly active, such as the Southern Cone of South America, are not covered to the extent that their importance in maize production might have suggested. This is particularly true of Argentina, for which very little information is reported. Africa, on the other hand, receives extensive coverage—reflecting the extent to which maize improvement research is a public sector effort and, in part, the large number of countries with maize research programs.

The country presentations are, in any case, quite brief and tend to focus on the development and commercial release of improved varieties and hybrids rather than the actual coverage and impact on yields of these improved genotypes at the farm level. In most cases, it has not been possible to provide much statistical information, particularly of a time-series nature, about the area planted with improved maize varieties and hybrids in individual countries.

The uninitiated might tend to think of maize breeding as a passionless, scientific enterprise. It certainly is scientific, but there are—as when one scratches the surface in other areas—strong differences in opinion among some scientists. The study attempted to strike a middle ground and stay with the facts as closely as possible.

There is plenty of work left to do—both to expand the breadth and depth of the coverage. I hope that this report serves both as an introduction to the subject and as a stimulus for further study.

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Preface

This first report on the development and use of improved maize genotypes in the Third World is modeled after the reports prepared periodically by Dana G. Dalrymple on the development and spread of high-yielding varieties of wheat and rice in the less developed nations (Dalrymple 1986*a,b*). While we are disappointed that this report is not as complete in scope or data coverage as those reports, we are pleased in the belief that it will be a useful resource for subsequent efforts.

Our original hope was to obtain reasonably accurate estimates of the use of improved, specifically identified germplasm, varieties, or hybrids emanating from the International Maize and Wheat Improvement Center, headquartered in Mexico and commonly known by its Spanish acronym, CIMMYT, and the International Institute of Tropical Agriculture (IITA), headquartered in Nigeria.

We planned to establish the genealogies of the varieties, hybrids, populations, pools, and lines being developed by these two international agricultural research centers. Having the known genealogies in hand would permit (1) more reliable estimates of the germplasm contribution of these two IARCs to national program efforts to increase maize production in the Third World, (2) more definitive concepts of which basic germplasm is most noteworthy in that production, and, perhaps, (3) identification of basic germplasm that might receive more attention in future maize improvement strategies.

The peculiar (as opposed to wheat or rice) characteristics of maize biology and its culture have complicated efforts to provide an accurate picture of the use of improved varieties and hybrids in developing countries. Nonetheless, we have assembled a sizable amount of anecdotal information, oral histories, copies of lists and unpublished reports, and copies of genealogies and pedigrees made from field books about breeding material extracted from, or combined with, other germplasm. But informative and fascinating as these particulars appear, their range in accuracy, completeness, precision, and scope will require additional investigation. Subsequent efforts might well concentrate on ferreting out more reliable information on cultivars or material being developed having known genetic relationships to germplasm from the IARCs.

There is a particularly strong need to investigate the origins and breeding methodologies used to develop the outstanding germplasm complexes that have contributed so much to the improvement of maize. Many of the detailed records on how these germplasm complexes were put together and what mating and selection systems were employed are still available from field books and unpublished reports. Some of the details are missing, however, and attainable only from those researchers and breeders who put the materials together in the first place. Many of these people have retired and some have died. Thus, it is unlikely that the necessary records about the origins and handling of these germplasm complexes will be preserved much longer. If the formation of these outstanding gene pools and populations and the methodologies used to improve them are to be documented, it must be done promptly.

The original draft of this study has been considerably modified through the additional information and comments provided by CIMMYT and IITA and by several national maize programs in Asia, the Middle East, and Africa. Several CIMMYT and IITA maize publications released in 1986 and 1987 have provided new information on germplasm development in developing countries. National production statistics published by FAO have been added in chapters 1 and 4. The statistics on the use of improved genotypes come from a CIMMYT survey conducted in 1985-86 on commercial seed production in developing countries (CIMMYT 1987). Even with these data additions, there is still inadequate information on germplasm development and use for many countries.

Numerous maize researchers in developing and developed countries have given generously of their time in interviews and correspondence. We are most grateful to them. Various drafts of this report were reviewed by research leaders at CIMMYT, IITA, and several private plant breeding companies. To them we extend our profound thanks. A special expression of gratitude goes to Dana G. Dalrymple for his encouragement, guidance, and thoughts throughout this project.

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Summary

Maize is the second most important cereal crop in the world overall, after wheat and before rice. In the developing world, maize ranks third, after rice and wheat. In total, there are 80 million ha planted with maize in developing countries. This represents 60% of the world's maize area, though only 40% of global production is harvested from Third World maize lands. Tropical and subtropical environments cover 65% to 70% of this area and temperate environments cover the remainder. Four countries account for 67% of total Third World maize production: China, Brazil, Mexico, and Argentina.

The biology of maize and its population structure are vastly distinct from those of wheat and rice. The ramifications of these differences are reflected in (1) the use of breeding materials and methodologies, (2) technology and capability of seed production and distribution, and (3) local customs and conditions pertinent to grain production and consumer uses of maize. Improvement of maize germplasm for local, national, or international programs may be accomplished by emphasis on population improvement, concentration on hybrids and inbred lines, or modifications of either or both approaches.

Maize research in developing countries received an important impetus from the collaborative maize improvement programs established during the 1940s and 1950s by the Rockefeller Foundation and the governments of various developing countries. One of the first maize research efforts supported by the Rockefeller Foundation was the collection, classification, and preservation of the native maize races in Latin America and the Caribbean—centers of origin for maize. The best germplasm collections were assembled into breeding populations and improved for yield and various agronomic traits; these populations were then shared with selected national programs in the Americas, Asia, and Africa. A handful of these germplasm complexes introduced substantial new amounts of useful genetic diversity into national maize research programs, especially in Asia and Africa, where the genetic base of national breeding materials had become very narrow. These germplasm introductions accelerated progress in many maize breeding programs, and literally hundreds of improved varieties and hybrids have been developed using germplasm obtained through international exchange.

The International Maize and Wheat Improvement Center (CIMMYT) and the International Institute of Tropical Agriculture (IITA), established in the mid-1960s, represent the "institutionalization" of many of the international research and training activities pioneered during the 1940s and 1950s by the Rockefeller and Ford Foundations, FAO, and USAID. During the past two decades, the international agricultural research center (IARC) system has greatly expanded the amount and scope of international agricultural research. Similarly, developing countries, impressed by the green revolution gains in wheat and rice, have markedly expanded their investments in national agricultural research systems, including maize improvement research.

Today, CIMMYT and IITA serve as research hubs of large maize improvement networks involving hundreds of maize scientists in over 100 developing countries. Both IARCs operate large (and growing) maize research programs. Through international testing programs, vast amounts of improved maize germplasm are distributed for evaluation and use by national breeding programs. Each year, tons of seed for experimentation are shipped by CIMMYT

and IITA to hundreds of national collaborators throughout the world. Both IARCs make their seed freely available to bona fide maize researchers; preference, however, is given to collaboration with public sector maize research organizations. Of the two IARCs, CIMMYT has the most widespread maize improvement program, with collaborative relationships with more than 80 countries in Latin America, Asia, and Africa. IITA has maintained a regional focus in its maize improvement work, concentrating on the germplasm requirements of sub-Saharan Africa.

The complex genetic backgrounds of the new maize types developed, or being developed, preclude a simplistic compilation of data that would attribute increased yield or production to the use of CIMMYT and IITA materials. The improved maize germplasms developed and/or distributed by CIMMYT and IITA do not have a single common characteristic—such as the dwarfing habit so obvious in rice and wheat—to facilitate the tracking of production data. Even so, this report shows that developing countries have released hundreds of varieties and hybrids based on CIMMYT and IITA germplasm, with CIMMYT being a more dominant germplasm contributor. IITA's streak-resistant germplasm has been extremely valuable to national maize programs, especially in sub-Saharan Africa. Some of IITA's tropical inbred lines and hybrids are also showing promise in maize production zones in sub-Saharan Africa and on other continents. In some instances, increased production from the use of CIMMYT and IITA maize stocks has been noteworthy. In other cases, the results are nebulous at best.

In the temperate areas and, to some extent, in the subtropical areas of the developing world, germplasm from the USA and Europe has been widely used to develop improved genotypes. In the subtropical areas, however, temperate germplasm has generally lacked sufficient resistance to stalk and ear rots and various foliar diseases. To overcome this deficiency, tropical and subtropical germplasms with greater resistance to these diseases have been introgressed to strengthen the disease resistance of genotypes based on temperate germplasm.

Improved genotypes have been developed and released for most lowland tropical and subtropical areas of the developing world. These materials have higher yield potential and superior agronomic characteristics than traditional maize varieties. The improved genotypes are shorter in stature than traditional local materials and partition more of their total dry matter production to grain. Their resistance to foliar diseases and stalk and ear rots is also generally superior to traditional varieties. There is still a need to develop genotypes for intermediate and highland environments and for those areas characterized by serious environmental stresses, especially drought.

CIMMYT has estimated that in 1985-86 approximately 50% of 80 million ha in developing countries was planted with commercial seed of improved hybrids and improved varieties. In China, Brazil, and Argentina—which have 30 million ha of maize land—commercial seed is used on over 75% of the total maize areas. However, when these three countries are not included in the statistics, only about 26% of the total maize area in developing countries is planted with commercial varieties and hybrids. While improved genotypes have been developed that are suitable for much of the area still growing local varieties and landraces, other impediments—especially nonavailability of commercial seed and fertilizer—restrict their adoption.

Although improved genotypes have been developed and released for most of the major production environments, the absence of effective seed production systems has seriously restricted the diffusion of these materials at the farm level. Unfortunately, in all too many countries, the absence of functioning maize seed sectors has severely restricted the diffusion of improved varieties and hybrids at the farm level. This, in turn, has seriously reduced the returns that would have otherwise accrued to society from the investments made by developing country governments in maize improvement research. Clearly, nonfunctioning maize seed sectors in all too many developing countries have had a tremendous cost in terms of foregone maize production and improvements in productivity.

Since the late 1970s, private sector involvement in maize research and seed production in the developing world has grown markedly. Initially, private maize seed companies concentrated their activities in temperate-zone developing countries where U.S. Corn Belt hybrids do well. Increasingly, however, as more improved germplasm for tropical and subtropical areas has become available (developed largely through national and international public sector research efforts), private sector maize research and seed production initiatives have expanded in those countries with subtropical and tropical maize production environments where strong commercial demand exists for maize.

1. BACKGROUND ON MAIZE

MAIZE IN THE WORLD ECONOMY

Area and Production

Maize, with a global harvest in 1985 of 449 million metric tons from 133 million ha, ranked second to wheat (with hulled rice third) among the world's cereal crops (FAO 1986). Some 70 countries produce maize on 100,000 ha or more; 53 of these are developing countries. Developed market economies account for 30% of the global maize area but provide 50% of total production, due to average yields that are three times higher than the world average. Developing countries account for approximately 60% of the total world maize area but produce only 40% of the global harvest. During 1983-85, developing countries produced an average of 169 million tons (t)[1] of maize per year (CIMMYT 1987). Four countries accounted for 67% of the Third World's maize production: China (68 million t), Brazil (21 million t), Mexico (14 million t), Argentina (10 million t).

In total, there are 80 million ha planted with maize in developing countries. Lowland tropical environments account for 32 million ha or about 40% of the total area planted with maize in the developing world. These tropical maize growing environments are found in the lowlands of eastern and western Africa, south of the Sahara; the plains and delta areas of South Asia; Southeast Asia; Central America and parts of Mexico; and the lowland areas in Andean countries of South America and Brazil. Temperate environments (e.g., Argentina, Chile, China, Middle East), accounting for 24 million ha (30%) of the total maize area, are in developing countries. Subtropical and intermediate-elevation zones (South Asia, Middle East, North Africa, Mexico, Brazil, East Africa) account for approximately 18 million ha (22%) of the developing country maize area. Highland zones above 1,500 m (subtropical-temperate) in Mexico, Central America, Andean countries, East Africa, and Himalayan countries account for about 6 million ha (8%) of the total maize area in the Third World.

During the period 1961-65 to 1983-85, world maize production increased by 182 million t (CIMMYT 1987). This is a 4.0% annual growth rate and represents a 84% increase in world supplies. Most of this growth was achieved through yield improvements. In developing countries—though there was considerable regional variation—yields increased at a 2.8% annual rate, while the overall area expanded by 1.2% per year. China reported the most rapid growth in yields among major producers, with a 4.8% per annum rate of gain in yield per year. In sharp contrast, yields in sub-Saharan Africa increased at only a 0.9% yearly rate. For the developing countries as a whole, production is not increasing as fast as demand, and imports are rising (Vocke 1987).

Utilization

Maize is used in more ways than any other cereal: as a human food, a feed grain, a fodder crop, and for hundreds of industrial purposes. Its grain, stalk, leaves, cobs, tassel, and silks all have commercial value in most settings, though that of the grain is the greatest. The most diversified use of maize occurs in the United States, where over 1,000 products in a typical supermarket contain maize in some form or another in their makeup.

Worldwide, about 66% of all maize is used for feeding livestock, 25% for human consumption, and 9% for industrial purposes and as seed (CIMMYT 1984). In the developing world, however, roughly 50% of all maize is consumed by humans as a direct food source, 43% is for livestock feed, and the remainder is used for industrial and seed purposes (CIMMYT 1984). Although maize is important as a food crop in Mexico,

[1]All ton measurements are for metric tons.

Figure 1. Cultivating maize interplanted with other crops in Honduras. Source: CIMMYT.

Central America and the Caribbean, the Andean countries of South America, and sub-Saharan Africa, it is increasingly important as a feed grain in the newly industrialized countries of the Pacific Rim, the middle-income countries of Latin America, and the major oil-exporting countries.

SOME BASIC BIOLOGICAL CHARACTERISTICS OF MAIZE

Botanical Classification

Maize, *Zea mays* L. spp. *mays*, is a diploid (2n = 20) member of the tribe *Maydeae*, *Tripaceae*, or *Androponeae* (depending upon one's taxonomy), subfamily Panicoideae of the Gramineae. Its native distribution was restricted to the New World. Although the origins of maize remain elusive, it is well established that at least one kind of maize originated in the Valley of Mexico (Galinat 1971, 1977; Mangelsdorf et al. 1964, 1967; Mangelsdorf 1974). The archeobotanical evidence indicates that for several thousand years the pencil thin cobs of this primitive plant nourished its cultivators. Subsequently, new characteristics were added to this primitive cultivar, presumably from the related wild grass teosinte, and the domesticated genotypes began to assume the proportions and characteristics of present day maize land races. While reasonably close, the affinity of maize with *Tripsacum* L. is much less than with the teosinte. However, there is little doubt that maize, teosinte, and *Trisacum* share differing kinds and amounts of common genetic information.

Climatic Adaptation

Maize is grown in more diverse areas of the world than any other major crop. It is grown from sea level to 3,800 m elevation near Lake Titicaca in Bolivia and Peru, from desert oases to zones having 11,000 mm rainfall (Patiño 1956) along the western coast of Colombia, and from about 42° latitude S near Chiloe Island to about 50° latitude N on the Gaspe Peninsula of New Brunswick, Canada. It is cultivated from northern Europe and Russia to South Africa, eastward through Asia, the Himalayas, China, Southeast Asia, and the Pacific Islands. The genetic differences are vast among the kinds of maize grown among the distinct locales of these disparate areas. The diverse but particular conditions of soil, temperature, rainfall, relative humidity, photoperiod, and light intensity have all imposed selection pressures on the kinds of maize at each site.

INFLUENCES ON MAIZE IMPROVEMENT

In the industrialized societies, maize is bred for mechanized agricultural technologies, highly engineered milling and processing plants, sophisticated marketing strategies, and various consumer tastes and choices. These industrial endeavors are supported by, and are part of, a well-functioning and highly developed infrastructure. However, in those areas in which sufficient levels of development do not exist, the farmer has played an important role in the evolution of the kinds of maize being grown. This is particularly so when maize is used for direct human consumption rather than as animal feed or industrial use.

Selection Criteria and Plant Structure

The structure of maize lends itself to stringent and repeated scrutiny of each individual plant by its cultivators. Thus, selection of a desired type may be of exceedingly high intensity. This kind of selection is facilitated by the large physical structure of the plant; all the above-ground parts are easily observed for length, width, thickness, color, pubescence, position, and numbers of plant parts and their shapes, angularity or idealized architecture, husk cover, shank characteristics, maturation rates, and reaction to insects, diseases, or other stresses and perturbations.

The ear is particularly susceptible to selection criteria. Each ear is harvested by hand and through repeated handling in the husking, drying, storing and shelling process, human preference comes to bear for grain type. These traits include grain size, shape, color, starch texture, characters pertaining to appearance, cleanliness, and desirability for ultimate use. The successes of the efforts are evident from the extant variability among the thousands of indigenous strains of maize found throughout the world.

Selection Criteria and Use

Superimposed upon the selection pressure of environments or biological stresses, such as temperature or insects, are the additional selection criteria pertinent to the local uses of the grain or other plant parts. Maize is used as a staple in many forms of comestibles: fermented and nonfermented drink, porridges, tortillas and other baked products, cooking oil, dyes, animal

Figure 2. Preparing tortillas from maize in a Latin American home. Source: CIMMYT.

and poultry feedstuffs, fodders, medicinals, ceremonial and religious essentials, physical support of a companion crop in multicropping systems, toys, dolls, effigies and other household or community symbolisms, and raw material for a host of industrial products.

Selection Criteria and Population Structure

Maize is a highly evolved cross-fertilizing annual. Generally, each plant is an indigenous or intermating entity that is unique by virtue of its hybrid nature, having originated from a male gamete of one plant and a female gamete from another. While the plants in such a population may be phenotypically homogeneous as a consequence of selection, the individual genetic condition of each plant is essentially heterozygous. However, when two completely homozygous inbred lines are used to form an F_1 hybrid, all the progeny in that first generation will be genetically identical. Subsequent generations will revert to individually distinct heterozygous plants comprising all the possible combinations of the alleles of genes from the inbred lines. This is distinct from what occurs in self-pollinating species, such as wheat or rice, in which a population is largely homozygous: each plant is identical to another. In some self-pollinations, an outcross—an F_1 hybrid—occurs and the approach to homozygosity of the progeny from any heterogenous individual (the F_1) increases by one-half in each successive generation. However, the population will then contain a mixture of distinct homozygous lines and a decreasing number of heterozygous individuals.

The monoecious character of maize (separate male and female inflorescences on the same plant) facilitates controlled pollination. Thus, many of the breeding methods used for self-pollinating species are used with maize for certain qualitative traits and conditions, such as simply inherited reactions to diseases. Quantitative characters (yield) and the kinds of dominant, additive, or interactive gene action controlling such traits and hybrid vigor have led to the development of numerous breeding methodologies. These have been used to develop inbred lines for hybrids, synthetics, composites, or improved varieties, and for population improvement as source materials. (See appendix A for a brief definition of hybrids, synthetics, and composites.)

Infrastructure and Plant Breeding

Sustained production of high-yielding hybrids requires an adequate technological and agricultural infrastructure comprised of credit, transportation, processing, marketing, educational, and other agricultural support systems. Areas lacking these facets are either unsuitable or less developed for hybrid production. In these latter cases, maize is usually produced from indigenous races, improved varieties, synthetics, or from varietal crosses. Indeed, most national programs in the developing world produce improved maize genotypes via these latter systems rather than by the use of single, three-way, or double-cross hybrids.

Commercial breeding efforts are sustained only in the more advanced maize growing areas, as investment returns are made only by repeated seed sales of hybrid seed. Where farmers save or sell seed from a hybrid for replanting, yield potential decreases appreciably, and agronomically undesirable recombinant characteristics are expressed in the next segregating generation. Neither the farmer nor the marketplace will tolerate this. Thus, maize improvement programs in less advanced areas are based on improved varieties, modified hybrids, synthetics, or varietal crosses. These are usually produced by governmental or international agencies mandated by agricultural development needs rather than the requirement to make a profit. These latter agencies also develop single crosses or other hybrids for commercial production, but when seed sales volume reaches an appropriate level, commercial companies soon appear and target hybrid seed sales on more specific areas of their product's adaptability than is normally done by a development agency.

The presence (or absence) of effective seed production organizations is the major determinant of the type of maize varieties used by farmers around the world. Where adequately developed seed industries exist, F_1 hybrids are generally the "standard." Where seed industries are less well-developed and/or where farmers grow maize as a subsistence crop for home consumption, open-pollinated varieties, often unimproved, are the dominant types.

2. INTERNATIONAL GERMPLASM DEVELOPMENT PROGRAMS AND NETWORKS

EARLY MAIZE GERMPLASM EFFORTS AND APPROACHES

The rapid spread of hybrid maize production in the United States during the 1940s was accompanied by the disappearance of indigenous maize varieties. The loss of those genetic resources, products of hundreds or thousands of years of evolution under domestication, could restrict future maize improvement and deprive us of genes of great potential importance. There was a growing realization that the genetic diversity among native strains and varieties in Latin America and the Caribbean would also become extinct with increased planting of improved varieties and hybrids that had begun in those areas. Concern for this situation led to concerted efforts beginning in the 1940s and 1950s to collect, preserve, and classify native maize varieties and strains in Latin America. These early efforts in maize germplasm collection and classification led to the identification and development of some outstanding germplasm complexes in the Americas, which later also proved to be very valuable to the maize breeding programs in Asia and Africa.

Germplasm Collections in Latin America

The Cooperative Maize Improvement Program of the Mexican Ministry of Agriculture and the Rockefeller Foundation, initiated in 1943, immediately began collecting the native maize varieties and strains throughout Mexico to serve as a germplasm base for improvement. The myriad kinds of variability in this hodgepodge of diversity was reduced by several criteria into small groups containing similar or like kinds of recognizable traits. These smaller groups were defined and characterized as races (Wellhausen et al. 1952). Similar procedures were subsequently used in other areas to describe on a preliminary basis the races of maize in the New World (Brieger et al. 1958; Brown 1960; Grant et al. 1963; Grobman et al. 1961; Hatheway 1957; Ramirez et al. 1960; Roberts et al. 1957; Stakman et al. 1967; Timothy et al. 1961, 1963; Wellhausen et al. 1957).

Over 280 races were described, with some overlap, but for the first time the variation in an important world crop was classified into easily recognized and workable groups. Additional races in both the New and Old Worlds have been described subsequently, but these studies are generally of restricted geographical scope. (See Brown and Goodman 1977; Goodman 1978; Hallauer and Miranda Fo 1981.)

The similarity of many of the races and their evolutionary histories have led to additional subsequent groupings of races into groups or racial complexes, mostly by Goodman and his coworkers. (See Goodman 1978 and Brown and Goodman 1977.) The identification of these complexes, coupled with the results and experience from plant breeding studies, has begun to enable the identification of superior kinds of germplasm for rapid improvement of yield and other characteristics.

The vast array of diversity in this material, the specific requirements for adaptation to local environments, demands by local markets, and preferences dictated by human consumption added impetus to the need for collections. The obvious similarity of certain types of maize in the Caribbean Basin to those of the eastern coast of Mexico, and of maize in northern and western South America to either western Mexico or southern Mexico and highland Central America, indicated that collections outside Mexico would also be

Figure 3. Genetic diversity of maize is expressed in these highly varied ears. Source: CIMMYT.

essential. Similarly, the Cooperative Maize Improvement Program of the Colombian Ministry of Agriculture and the Rockefeller Foundation begun in 1950 reiterated the need to collect maize beyond the Colombian border. Activities by commercial seed companies and universities in the industrialized countries during this time period also stressed the need for collection (Brown 1960; Cutler 1946; Hatheway 1957).

The National Academy of Sciences-National Research Council (U.S.) formed the Committee on Preservation of Indigenous Strains of Maize to sponsor a project that would collect, preserve, and study for future use as many land races and varieties of the Americas as possible (Clark 1954; 1956). Additional support and cooperation for this work was received from the Rockefeller Foundation, numerous governments, and several universities. The collections were made, studied, and described in a "Races of Maize" bulletin series. These germplasm collections were to be maintained and made available to qualified scientists for additional study, research, and maize improvement. The Central American and Caribbean collections were to be maintained and distributed at Chapingo, Mexico; those from western and Andean South America from Venezuela through Chile at Medellin, Colombia; and those from eastern South America and the Guianas at Piracicaba, Brazil. As a safeguard against loss, duplicate samples of the collections were to be sent through the USDA facilities at Glen Dale, Maryland, and eventually put in long-term storage at the National Seed Storage Laboratory at Fort Collins, Colorado. However, the reality of those events has been less than satisfactory (Goodman 1984; Timothy and Goodman 1979).

Development of Improved Varieties and Hybrids in Latin America

During the 1940s and 1950s, several national maize improvement programs made appreciable impact in the development and distribution of improved varieties and hybrids. The Rockefeller Foundation initiated a Central American Corn Improvement Project in 1954

(Stakman 1967). Particularly notable national maize breeding programs were found in Mexico, Colombia, Cuba, Venezuela, Brazil, and Argentina. Materials from these programs made considerable contributions to breeding stocks and are still being used.

An improved yellow flint variety, Venezuela-1, was developed by several cycles of mass selection from two Cuban varieties (Langham 1942). Although not stated, this Coastal Tropical Flint has Cuban Flint Cateto in its background. The development in Colombia of several varieties, Colombia 1, Colombia 2, and ETO (Chavarriaga 1966), were of considerable worldwide importance. That germplasm is an important component of many breeding programs of the world.

Colombia 1 and Colombia 2, yellow and white varieties, respectively, were both developed from a series of crosses among three sources followed by selection for combining ability among sib-mating/progenies. The three sources of germplasm were the yellow flint, Venezuela 1; the white Colombian race predominantly from the Cauca Valley, Blanco Común; and a white local variety from near Urrao, Blanco de Urrao. Blanco de Urrao apparently was made up primarily of the Colombian races, Común and Chococeño. Subsequently, Venezuela 1 and Colombia 1 were subjected to a host of controlled pollinations from lines, hybrids, and varieties from Venezuela, USA, Brazil, Mexico, Puerto Rico, Argentina, and Cuba. Additional testing, selection, and hybridization of this material led to the selection of 12 ears used to form ETO, a yellow-flint synthetic variety (Chavarriaga 1966).

One consequence of the broad genetic background of ETO was that it had segregating kernel colors. By selfing and test crossing onto a white tester, a large number of pure white ETO lines were selected and recombined to form ETO blanco. Another consequence of the diversity within both ETO and ETO blanco was that it was possible to develop double-cross hybrids whose four lines derived entirely from within one or the other variety. The yield potential of material from these varieties was such that they are still important components of many breeding programs.

In the early stages of the Mexican Government-Rockefeller Foundation Program, it was apparent that seed multiplication and distribution of the better landraces might clearly give rapid and substantial increases in maize production in the high plateau. From 240 collections in the States of Guanajuato, Jalisco, and Michoacan, 15 superior collections of early, medium, and late-maturing materials were selected for immediate distribution and as foundation material for later development of superior synthetics and hybrids. The improved yield of these materials ranged from 15% to 160% above comparable local varieties (Wellhausen 1947).

The Mexican-Rockefeller research group developed the composite variety, Rocamex V-7, by mass selections in a collection from near Actopan, Hidalgo, originally arising from a natural cross of cylindrical dents from the lowland tropics with high-altitude maize (conicos) from the Central Plateau (Wellhausen and Roberts 1948). Several other varieties were developed using this procedure (Roberts et al. 1949; Wellhausen 1950), as were those based on improved collections of the Race, Olotón (Neves et al. 1957).

Early hybrids released by the Mexican-Rockefeller Program for tropical regions were Rocamex H-501, H-502, H-503 (Reyes et al. 1955). These double-cross hybrids were produced by crossing seven inbred lines extracted from several populations of Tuxpeño. Two of the collections were from the State of Veracruz, one from the State of Coahuila, and one from the State of San Luis Potosí. The hybrids were all closely related. One inbred (T3) was common in all three hybrids, and two of the three lines were common to two hybrids. The hybrids were reported to yield 20% to 25% more than the open-pollinated varieties they were to replace. Other hybrids were released for the higher elevations of the Central Plateau. These were based largely on inbred lines from the races Celaya and Bolita (Secretariat de Agricultura 1955).

Maize Research Activities in Asia

During the 1950s, various other organizations—USAID, FAO, USDA—also introduced a large number of U.S. F_1 hybrids into Asia. For the tropical areas of Asia, the U.S. hybrids failed to gain a foothold. First, the U.S. materials were not adapted to the tropical and subtropical conditions of climate, diseases, and insect pests. Second, the inbred lines in the double crosses were generally too weak to withstand the harsh production environments of tropical areas. Third, the yellow dent grain of the U.S. hybrids was not the preferred grain types. However, the U.S. Corn Belt dents were used extensively in the temperate areas of Asia; they were also used in subtropical and tropical maize improvement programs to take advantage of several desirable traits, though the gene frequency of the temperate materials was usually less than 50%.

In 1956, the Government of India and the Rockefeller Foundation signed a memorandum of understanding that was to have considerable significance for the improvement of maize in Asia. The agreement provided for a cooperative effort in developing a postgraduate school at the Indian Agricultural Research Institute and for cereal improved work on several crops, including maize. The maize improvement work of the Rockefeller Foundation-Indian Agricultural Program (RF-IAP) began in 1957 and made rapid progress. By the early 1960s, the RF-IAP program was receiving many requests from neighboring countries for genetic stocks and research assistance. Clearly, such international assistance was beyond the scope of IAP. Therefore, a separate organization, the Inter-Asian Corn Program (IACP) was established in 1964, with its headquarters first in India and after 1966 in Thailand.

The IACP eventually included 16 countries stretching from Afghanistan to South Korea and operated continuously from 1964 to 1975. Through IACP a large amount of improved germplasm—mainly from the Americas—was introduced into the national maize programs of Asia during the 1960s. IACP regional trials and nurseries began in 1969. These uniform yield trials contained improved varieties and promising breeding materials from participating national programs. Initially, most of the entries in the regional trials came from India. Later, the Pakistani and Taiwanese maize programs supplied outstanding subtropical materials, and Thailand and the Philippines supplied outstanding tropical materials (personal communications, T. Izuno and B.L. Renfro).

Exchanges of Breeding Material and Informal Cooperative Networks

During the 1950s the exchange of breeding material, lines, and synthetics between the joint Rockefeller-Government maize programs in Mexico and Colombia—as well as germplasm exchange with maize programs elsewhere—led to identification of selected germplasm that combined exceptionally well with one another, e.g., ETO with Tuxpeño, and Montaña with Chalqueño and Tuxpeño. Indeed, the results of racial crosses in the Colombian program indicated that the race Montaña, including Ecu 573 from Ecuador, should combine well with germplasm in Kenya. Therefore, Ecu 573 was sent from Colombia to Kenya and crossed with Kitale II. It resulted in greatly increased yields and formed the base for continued improvement. Similarly, the Mexican program had identified superior breeding materials for many parts of the world. Many of these were races, improved varieties, or composites of generally identifiable racial backgrounds (Wellhausen 1978).

The influence of the Colombian and Mexican programs was particularly strong in Central America, and to an appreciable degree in the Caribbean Basin. Initial exchanges of breeding material and informal technical cooperation led to increasingly close coordination of breeding efforts and integration of material. Consequently, numerous varieties, synthetics, and hybrids were developed and distributed within these regions. One of several important releases from this area was Tiquisate Golden Yellow, having appreciable germplasm from Cuba Oriente (personal communication, E.J. Wellhausen and E. E. Gerrish). Tiquisate Golden Yellow was widely grown in Thailand as "Guatemala" and as "Metro" in Indonesia and the Philippines. Yellow Salvadoreño was developed by mass selection in a varietal cross of Yellow Tuxpan and Cuba P.D.(MS)7 (Primera Reunion Centroamericana 1954). Both these varieties were important in the later development of Suwan-1, and Thai Composite #1 (personal communication, E. E. Gerrish).

These exchanges of information and breeding stocks, accompanied by sometimes spectacular increases in yield or improvement of other characteristics, led to an informal network of exchange and collaboration. Most often, an improved variety, or hybrid and its component lines, was used on one side of a cross with locally adapted material on the other. While many programs were releasing varieties or synthetics, there was ample opportunity to also release conventional or modified hybrids when seed production capability was suitable. The general trend of all this activity was greater awareness of the genetic background and racial composition of the breeding material.

Emerging Concepts of Germplasm Use and Breeding Methods

Superior inbred lines, single crosses, or improved varieties from one breeding program were often crossed onto these same categories of breeding materials in another area. This was expedient in the early stages of many programs in order to obtain better material rapidly for distribution to farmers. This also led to the recognition of certain germplasm as clearly superior to others. Consequently, superior germplasm was being distributed widely in many areas of the world. It was also becoming apparent that many parts of the world could not, and should not, sustain a full-fledged hybrid seed production and distribution program. Without a reliable supply of quality hybrid seed—and often no funds or credit to purchase these materials—hybrid maize use spread slowly in most maize-producing countries, even though farmers recognized the yield superiority of hybrids compared to their own varieties.

Beginning around the mid-1950s, there was growing awareness that the development of synthetic varieties from superior germplasm could serve many less-developed areas of the world. Breeding theory and methodologies indicated that appreciable improvement in maize could be attained by various recurrent selection schemes. These procedures could be applied to the existing superior germplasm stocks, varieties, races or racial groups, and composites. Here, the material from each breeding cycle has the potential of being released directly as a variety. This would allow for wide-scale distribution, even from farmer to farmer, without suffering losses in yield or agronomic desirability, and without having a sophisticated seed industry in place. Additionally, the material from each breeding cycle could also serve as an improved source from which to extract inbred lines for hybrid seed production to suit those areas having more advanced agricultural capability.

The combination of the above events or circumstances led to increased understanding about germplasm use. Certain lines or stocks were obviously valuable for insect or disease resistance, or for other agronomic characteristics in a particular situation. The outstanding races, varieties, or germplasm complexes that contributed greatly to yield were of complex background and genealogy. Diversity per se was no guarantee in contributing to hybrid vigor or high yield potential. It was impossible to systematically test all the maize collections to determine which would be most advantageous to use under the myriad growing conditions where maize was produced. Gradually, more effort was put into developing improved populations, as these could be used both in hybrid breeding programs as well as those concentrating on varietal development. Obviously, the important constituents of these programs were those races or germplasm complexes already recognized as being exceptional. These included ETO, Tuxpeño, Cuban Flint-Cateto, Coastal Tropical Flints, Celaya, Pepitilla, Chalqueño, Tiquisate, and Salvadoreño, to name a few. In addition, numerous studies of intervarietal crosses were undertaken by the Rockefeller Foundation-Government programs in Mexico and Colombia during the 1950s and 1960s to determine which other races and varieties would be most promising.

Refinements of Population Improvement Methods

Various types of recurrent selection programs at several locations in the Western Hemisphere were proving successful for improving maize varieties or germplasm complexes. Gains were shown for such traits as grain yield, stronger stalks and root systems, lowered plant and ear height, greater resistance to some diseases and insect pests, certain other physiological characteristics, and modifying environmental adaptation. Recurrent selection procedures provided many desirable features when applied to diverse germplasm varieties, complexes, or composites. By the 1960s, a number of the breeding programs using these techniques on widely grown varieties or on newly constituted composites (genetic mixtures of varying kinds and complexities) were obtaining appreciable gains in the traits being selected. A number of outstanding varieties were developed by the RF-Mexican program. Among these were Tuxpeño Crema I, Tuxpeño La Posta, and Tuxpeño-1 (E. C. Johnson 1974 and personal communication; E. J. Wellhausen 1978 and personal communication).

These events were conducive to the thought that compositing various germplasm sources such as varieties, individual indigenous collections, racial complexes, or elite breeding materials into new populations or germplasm pools would be an effective method to concentrate more desirable and diverse genes into fewer numbers of breeding materials. Subsequent population improvement by recurrent selection methods would then further concentrate the desired genes. These populations could then be released as improved varieties. Additionally, it was believed that these populations would serve as better sources of inbred lines (or at least reduce the number of stocks to be worked on) for hybrids than did the constituent individual stocks used in the original admixtures or composites. Consequently, there was considerable effort made in many breeding programs—including by the International Maize and Wheat Improvement Center (CIMMYT) and the International Institute for Tropical Agriculture (IITA)—to form composites from diverse germplasms.

ESTABLISHMENT OF INTERNATIONAL MAIZE IMPROVEMENT PROGRAMS

The successes of the Rockefeller Foundation, and later the Ford Foundation, in their cooperative agricultural programs in various Third World nations, led

Figure 4. A vivid demonstration of different plant heights resulting from experiments in improving the grain to stover (stalks and leaves) ratio of Tuxpeño Crema I maize. Tlaltizapan Maize Breeding Station, Mexico. Source: CIMMYT.

these two foundations to seek ways to institutionalize international agricultural research for basic food crops in developing countries. In maize research, an intermediate step in this process was the establishment through Rockefeller Foundation assistance of the Inter-American Corn Program for Latin America in 1960 and the Inter-Asian Corn Program for South and Southeast Asia in 1964. With the establishment of the international agricultural research centers, the Rockefeller and Ford Foundations channeled more of their international food research efforts through these organizations and eventually discontinued their support for the regional cooperative maize programs that had been established in the early 1960s.

In 1971, under the sponsorship of the World Bank, the United Nations Development Programme (UNDP), and the U.N. Food and Agriculture Organization (FAO), the Consultative Group for International Agricultural Research (CGIAR) was formed to support an expanded network of international agricultural research centers (IARCs) modeled after the first four. The CGIAR today consists of some 40 donor countries, international and regional organizations, and private foundations. It supports 13 nonprofit international agricultural research and training centers that focus on food production challenges in the Third World. In pursuing their mandates, the IARCs seek to provide national programs in developing countries with a range of products and services, such as improved germplasm, research procedures, training, consultation, and information. CIMMYT and IITA operate diversified research, training, and information programs designed to support and complement the work of national maize research programs.

At the time of their establishment in the 1960s, CIMMYT, IITA, and the International Center for Tropical Agriculture (CIAT) all had maize research programs that were descendents of various Rockefeller and Ford Foundation bilateral maize research efforts with developing country governments. Among the three IARCs, CIMMYT had the largest maize research program and considered that it had a worldwide mandate for maize improvement. In the early 1970s, CIAT opted to discontinue its maize improvement work and to rely on CIMMYT to supply improved maize germplasm to national programs in Latin America. The interest that CIAT did retain in maize was primarily concerned with its frequent intercropping association with climbing field beans (one of the CIAT mandated crops). In contrast, IITA has expanded its maize improvement program from an initial focus on the lowland humid tropics of sub-Saharan Africa to include intermediate-altitude regions of tropical Africa.

In recent years, CIMMYT and IITA have sought to improve their research coordination and collaboration between their respective maize improvement efforts in Africa. In 1980, two CIMMYT maize breeders were assigned at IITA to collaborate in the conversion of high-yielding varieties adapted to the lowland tropical areas to streak-resistant versions, and in increasing the streak resistance of Population 43, La Posta, a late, white dent material with good performance in sub-Saharan Africa. In 1985, CIMMYT and IITA also agreed to collaborate in a new joint germplasm improvement effort for the mid-elevation ecologies of eastern and southern Africa, in association with the University of Zimbabwe at Harare. (IITA has recently withdrawn from formal involvement as part of a new agreement with CIMMYT concerning regional division of responsibilities but will continue to be informally involved.) This program is using germplasm sources developed by IITA, CIMMYT, and various national programs.

CIMMYT's International Maize Improvement Program

In CIMMYT's early years, there was a carryover of personnel, breeding materials, and philosophies from the Mexican Government-Rockefeller Foundation program. But with their new international "mandate" the RF-Mexican maize team in Mexico took on new research responsibilities, added staff, and expanded the scope of their breeding materials and germplasm development objectives. From this milieu the concept evolved that CIMMYT would develop composites, improved populations, and varieties that could be used directly by national programs as varieties or as breeding sources for hybrids.

Using recurrent selection methods, CIMMYT began forming numerous composites of germplasm with different grain types and color for use in broad ecological zones. Some of the composites were formed indiscriminately; others were formed systematically on the basis of replicated trials; others on the basis of race, racial relationship, phenotypic characters, knowledge of the performance of related materials, and intuition (personal communication, E.C. Johnson, J.H. Lonquist, and E.J. Wellhausen). By the early 1980s, however, CIMMYT's selection schemes had become more formalized (Vasal et al. 1982).

Unfortunately, the exact kinds and amounts of each germplasm component used to make the composites or gene pools when the particular strain, line, variety, or other entity was incorporated—and the precise methodology employed at each step along the way—are not known. In some cases, these events could possibly be determined from field books and the recollections of those involved, but in other cases it is improbable that a satisfactory reconstruction of the methods and materials used could be made (personal communication, E.C. Johnson, E.J. Wellhausen). Generally in these matters, CIMMYT's published accounts are too vague to be of much value in tracing germplasm flow, breeding history, or determining precisely the constituents of a gene pool or population, except in a broad overview.

CIMMYT's Maize Improvement Program has assembled and improved a broad range of germplasm complexes. Using a half-sib recurrent selection breeding methodology and fairly mild selection pressure, CIMMYT has developed 24 normal maize and 13 quality protein maize (QPM) gene pools, classified according to zone of adaptation, maturity period, and grain type and color. (The QPM work has recently been evaluated in NRC 1988.) These gene pools have been assembled from CIMMYT's germplasm bank—with more than 10,000 collections mostly from Latin America—and germplasm supplied by maize scientists from other research programs around the world. Using the most promising germplasm in these gene pools and from other sources, CIMMYT has derived 24 normal and 10 QPM advanced populations that are suited to a range of climatic conditions (tropical, subtropical, temperate), maturity periods (early, intermediate, late); grain color (yellow, white); and kernel type (flint, dent, floury). See table 1 for details.

In a continuous cyclical process, CIMMYT's pools and populations undergo improvement for yield potential, protein quality, agronomic type, disease and insect resistance, and tolerance to stresses such as drought and aluminum toxicity. In Mexico, these materials are screened for resistance to major foliar diseases, stalk

Figure 5. Dr. Surinder K. Vasal, CIMMYT plant breeder, who played a major role in developing quality protein maize. Source: CIMMYT.

and ear rots, and various ear and stalk borers. Additional disease screening for downy mildew, corn stunt, and maize streak virus is carried out through collaborative research projects with institutions located in areas outside Mexico that are more conducive to this work. Improved genetic sources for specific resistances to various diseases and insects and for tolerance to certain environmental stresses associated with drought, cold, heat, and acid soils are also being developed.

CIMMYT's germplasms are made available to cooperators in national programs through informal sharing of germplasm from either the pools or populations and through the more formalized international maize testing program, which included International Progeny Testing Trials (IPTTs), Experimental Variety Trials (EVTs), and Elite Experimental Variety Trails (ELVTs). This international testing program presently involves cooperation with scientists in more than 80 countries, and each year, over 700 trials are shipped for testing at several hundred locations.

Currently, in each IPTT, the full-sib progenies of a particular population are tested at up to six locations around the world. In a given year, about 15 populations are tested. The results of those trials are used for two purposes. First, based upon information provided by the trial cooperators, CIMMYT breeders select the best 50 to 60 families for within-family improvement, recombination, and regeneration of each population for the next testing cycle. The second use of the IPTT results is for the development of experimental varieties (EVs). Site-specific EVs are derived from the best 10 families at each IPTT location. An across-location EV is also formed using the 10 best families across all IPTT locations. These varieties are advanced to the F_2 stage

Table 1. CIMMYT's advanced normal and quality protein maize populations tested regularly in international progeny testing trials

Population number	Name	Description
21	Tuxpeño-1	TLWD
22	Mezcla Tropical Blanca	TLWD
23	Blanco Cristalino-1	TIWD
24	Antigua-Veracruz 181	TLYD
25	Blanco Cristalino-3	TLWF
26	Mezcla Amarilla	TIYF
27	Amarillo Cristalino-1	TIYF
28	Amarillo Dentado	TLYD
29	Tuxpeño Caribe	TLWD
30	Blanco Cristalino-2	TEWF
31	Amarillo Cristalino-2	TEYF
32	ETO Blanco	SIWF
33	Amarillo Subtropical	SIYF
34	Blanco Subtropical	SLWD
35	Antigua-Rep. Domin.	TIYD
36	Cogollero	TIYD
42	ETO-Illinois	SLWD
43	La Posta	TLWD
44	Am. Early Dent-Tuxpeño	SLWD
45	Amarillo Bajio	SIYD
46	Temp. Amarillo Crist.	SEYF
47	Temp. Blanco Dentado-2	SIWD
48	Compuesto de Hugaria	TeEID
49	Blanco Dentado-2	TIWD
61	Early Yellow Flint QPM	TEYF
62	White Flint QPM	TLWF
63	Blanco Dentado-1 QPM	TLWD
64	Blanco Dentado-2 QPM	TLWD
65	Yellow Flint QPM	TLYF
66	Yellow Dent QPM	TLYD
67	Temp. Blanco Crist. QPM	SLWD
68	Temp Blanco Dent. QPM	SIWD
69	Templado Amarillo QPM	SIYD
70	Temp. Amarillo Dent. QPM	SIYD

Key

T	= Tropical	L	=	Late maturity
S	= Subtropical	I	=	Intermediate maturity
Te	= Temperate	E	=	Early maturity
F	= Flint	QPM	=	Quality protein maize
D	= Dent	Y	=	Yellow

and dispatched to cooperators in the form of an Experimental Variety Trial (EVT), each of which is evaluated at 30 to 50 locations worldwide. After the data from these trials have been analyzed, CIMMYT selects the top-performing EVs to prepare Elite Experimental Variety Trials (ELVTs), which are distributed to from 60 to 80 locations and conducted in much the same way as the EVTs.

Although the development of pools, populations, and open-pollinated varieties will remain a central feature of the CIMMYT maize program, in 1985 CIMMYT established a hybrid development program in response to growing national program requests for research collaboration and assistance. Information is being generated about inbreeding depression and heterotic patterns of CIMMYT's broad-based gene pools and populations. IITA has provided CIMMYT with over 500 inbred lines from its hybrid program.

The 1980s have also seen an evolution in the breeding programs of CIMMYT. More attention is being placed on developing new source populations with resistance and/or tolerance to specific problems: insects, diseases, drought stress, and mineral toxicities. In many cases, CIMMYT's new source populations are being developed using the superior fractions (for a specific trait) of CIMMYT standard populations. CIMMYT has also increased its work in germplasm development for highland areas (above 1,800 m) and for intermediate elevations (1,200 to 1,800 m) (in collaboration with the University of Zimbabwe).

IITA's Maize Improvement Program

The maize improvement program at the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria, was initiated in the early 1970s. Its major objective has been to develop high-yielding germplasm with increased yield dependability by emphasizing resistance breeding through recurrent selection. Initially, efforts were devoted mainly to developing improved germplasm with resistance to *Puccinia polysora* and *Helminthosporium maydis* for the lowland humid tropics. Two late-maturing white populations were developed initially: TZB (African and Latin American sources with Nigerian Composite B as the most important component) and TZPB (derived from CIMMYT's Tuxpeño Planta Baja Cycle 7). Varieties developed from these two populations have been released in Nigeria, Cameroon, Gabon, and Benin.

In 1975, work was initiated to develop germplasm with resistance to Maize Streak Virus (MSV), a disease currently confined to the African continent. This re-

Figure 6. Testing of IITA inbred lines, for use in developing hybrid varieties, at a savanna station in Nigeria. Source: CIMMYT.

search effort has been the major aim of the IITA maize program during the last decade (IITA 1986*a*). MSV is one of the most economically important diseases in Africa. It occurs over a wide range of ecologies, from sea level to 1,800 m elevation and from the humid forest zone to the dry savanna. Yield losses of up to 100% due to MSV have been recorded in many African countries. Because of the erratic natural occurrence of MSV, it was necessary to develop an artificial mass-rearing facility for the vector, *Cicadulina* spp., and techniques for uniform infestation in the field. Through this screening program, two sources of resistance were identified: the variety TZ-Y from IITA and the variety La Revolution developed by the French Tropical Agricultural Research Institute (IRAT) at Reunion Island. These two sources have been used to develop multigenic resistance to MSV. While resistant plants are not immune, they show reduced symptoms of MSV.

After the discovery of MSV resistance, an intensive breeding program was initiated to develop resistant germplasm (populations, varieties, and inbred lines) with different ecological adaptation, maturity, grain color, and texture. TZSR-W and TZSR-Y, late white and yellow semiflint populations adapted to the lowland tropics, respectively, were the first improved populations with MSV resistance developed at IITA. Since 1980, CIMMYT has also posted one or two maize breeders at Ibadan to work with IITA scientists in the conversion of additional germplasm to streak-resistant types. In addition to developing new streak-resistant populations to serve additional ecologies, the CIMMYT-IITA collaborative program has converted, through backcrossing, over 30 experimental varieties from more than a dozen existing CIMMYT populations that are well-adapted to African maize production conditions. Streak resistance is also being incorporated into some of the most widely grown commercial varieties from African countries through a backcrossing conversion program. Today, many streak-resistant maize materials are being made available to national programs through IITA's international testing program.

In 1979, IITA initiated a tropical hybrid development program to produce adapted, disease-resistant inbred lines with good combining ability for use by national maize programs in hybrid and synthetic variety development. The hybrid program was expanded in 1982 through a special project funded by the Government of Nigeria; it subsequently evolved into a joint IITA-Nigeria hybrid program. IITA is now giving more attention to transferring hybrid technology to other interested African countries such as Cameroon, Ghana, and Côte d'Ivoire.

A number of outstanding hybrids for tropical areas have been developed through this research effort (IITA 1986*b*). These materials are made available to national maize researchers through two international hybrid trials (white and yellow) that are distributed throughout Africa and in a growing number of countries of Asia and Latin America. Commercial production of these hybrids is already under way in Nigeria.

In addition to its work in hybrid development and the breeding for MSV resistance, IITA's maize improvement program has also concentrated on five other priority research areas:

1. *Combined resistance to MSV and downy mildew.* While downy mildew, *Peronosclerospora* spp., is not widespread in Africa, areas infested with downy mildew generally overlap those subject to streak virus

attack. White and yellow populations with combined resistance to the two diseases have been developed using downy mildew resistant sources from Thailand and the Philippines. These materials have been crossed with streak-resistant adapted materials. The level of resistance to the two diseases is high, and preliminary experiments have shown that the resistant materials have good yield potential. Inbred lines and hybrids with combined resistance to MSV and downy mildew are being developed; some of these materials are currently being used in Thailand and the Philippines (personal communication, S.K. Kim).

2. *Resistance to stem borers.* Work is in progress on resistance to the two major stem borers species found in West Africa: *Sesamia calamistis* and *Eldana saccharina*. Development of suitable artificial insect rearing and infestation techniques is still under way and little research impact has been achieved to date.

3. *Drought tolerance.* Breeding for drought tolerance was initiated in 1982 in Burkina Faso through the SAFGRAD/IITA collaborative project. (CIMMYT also participates in this work.) Breeding for early- and extra-early-maturing germplasm is emphasized, with agronomic research also being an important component. Issues of water conservation, soil fertility, and soil compaction are the major topics in the agronomy research program.

4. *Resistance to* Striga *spp.* This parasitic weed is becoming a serious problem in the expanding maize-growing areas of the African savanna. A good level of resistance has already been identified among different germplasm sources indicating that breeding for *Striga* resistance is possible. A number of sites with a high level of natural infestation have been identified as locations for screening. Work has also begun to develop laboratory techniques for artificial infestation.

5. *Breeding for the mid-altitudes.* The mid-altitude ecologies of sub-Saharan Africa have some of highest yield potential. Germplasm requirements for these zones included resistance to leaf blight (*H. turcicum*), rust (*P. sorghi*) and MSV. In 1978, IITA began to develop maize populations with resistance to these diseases, and these populations have been tested in 20 countries. In 1985, CIMMYT, IITA, and the University of Zimbabwe, Harare, launched a collaborative mid-altitude germplasm development program for maize-growing areas in eastern and southern Africa between 1,200 and 1,800 m elevation. Improved populations, inbred lines, and open-pollinated varieties with enhanced disease resistance for mid-altitude ecologies are being developed through this joint program. (As noted earlier, IITA has recently withdrawn from formal involvement as part of a new agreement with CIMMYT concerning regional division of responsibilities but will continue to be informally involved.)

While the programs outlined in this chapter are, in the first instance, designed to help developing nations, the genetic products may also prove to be of value in breeding programs in developed nations. One example of the potential is provided in a recent article by Holley and Goodman. (The abstract is reproduced in appendix B.)

3. RECENT RELEASES AND USE OF IMPROVED MAIZE MATERIALS

This chapter provides a preliminary status report of the recent releases and uses of open-pollinated varieties and hybrids in 57 developing countries. The country reports probably overemphasize the germplasm contributions of CIMMYT, IITA, and predecessor international programs, such as those of the Rockefeller Foundation. This is primarily because more information is readily available from these international organizations than from national programs. It is hoped that future efforts to trace the use and impact of improved maize genotypes will help to fill in the informational gaps that are contained in this report.

SUB-SAHARAN AFRICA

Eastern and Southern Africa

ETHIOPIA

Maize is produced throughout Ethiopia in temperate as well as tropical environments, with the bulk of production concentrated in the southern, southwestern, and western regions. During 1983-85, approximately 1.2 million t of grain were produced annually on 850,000 ha, with national yields averaging 1.4 t/ha. Among the major cereals, maize ranks first in total production and in yield; it ranks fourth in total area behind Tef (*Eragrostis abyssinica*), barley, and sorghum. Almost all of the maize produced is used for human consumption.

Maize research is conducted by the Institute of Agricultural Research (IAR) and by the College of Agriculture (Debelo 1985). Both CIMMYT and IITA report collaboration with national scientists. Germplasm development efforts are directed toward the production requirements of three major zones: (1) areas with a short rainy season or erratic rainfall requiring early-maturing and/or drought-tolerant materials, (2) areas with additional rainfall requiring intermediate-maturity materials, and (3) late-maturing materials suitable for areas with a long growing season and ample rainfall. Breeding efforts to meet the needs of these different moisture regimes include the development of open-pollinated varieties as well as hybrids with resistance to *H. turcicum* and *P. sorghi*. An early-maturing, open-pollinated variety developed from this work was submitted in 1985 to the National Variety Release Committee for final approval.

A national seed program was implemented in 1978 with the establishment of the Ethiopian Seed Corporation (ESC). Large-scale seed production and distribution has been carried out since 1980. In 1985, the ESC reported seed sales of 11.8 t; of this total, 7.5 t was commercial seed, not certified but field approved. IITA reports supplying the ESC with 2 t of TZSR-1 and 200 kg of TZESR-W for multiplication and distribution to farmers in a new settlement area where maize streak virus is widely present (personal communication, Y. Efron). The ESC also has initiated production of two hybrids (8321-18 and 8322-13) developed at IITA.

KENYA

Maize is the major staple for Kenya's population, and more than 90% of this maize is produced by small-scale farmers. During 1983-85, approximately 2.4 million t of grain were produced annually on 1.5 million ha, with national yields averaging 1.5 t/ha. In addition, some 100,000 t of maize were imported annually during 1982-84.

Maize research in Kenya began in colonial times and has continued to evolve since independence. Germplasm development is directed toward four major agroecological zones (Ochieng 1985):

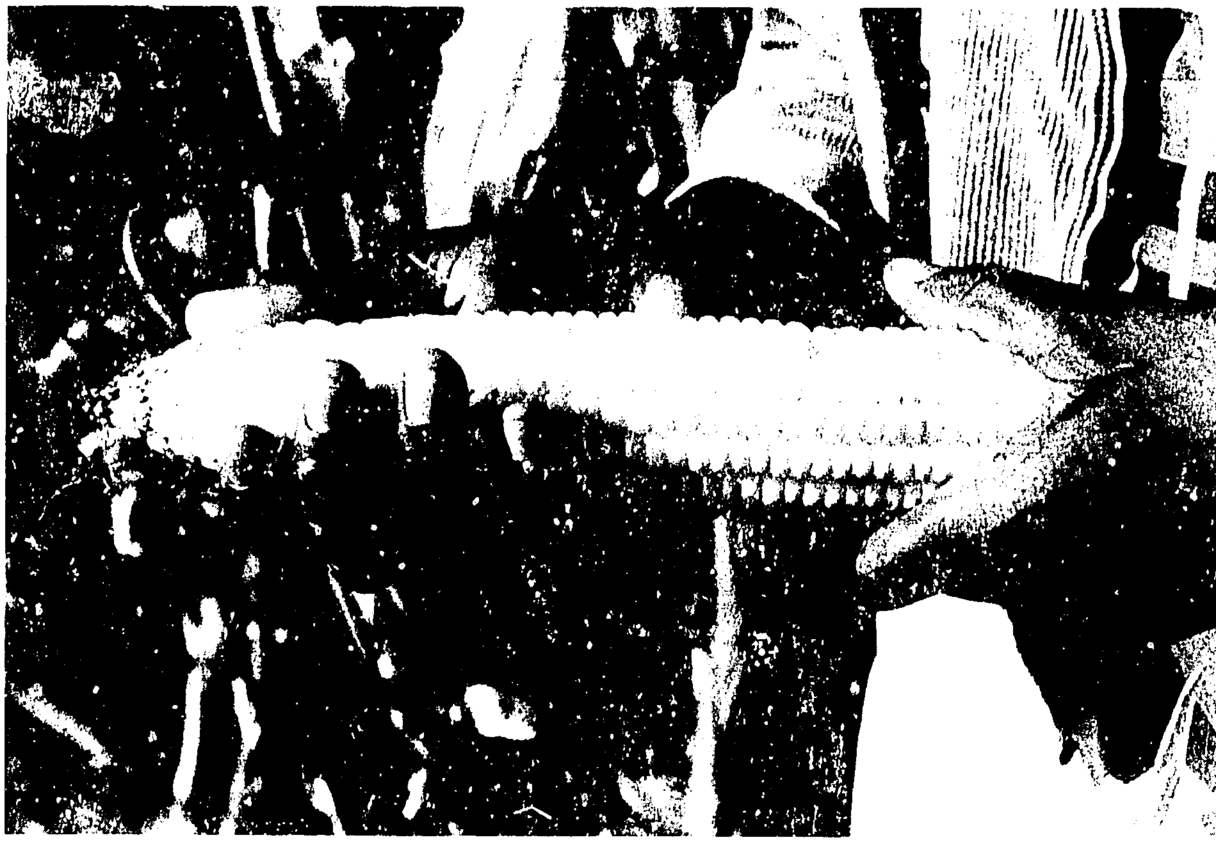

Figure 7. Ear of hybrid maize developed in Kenya. Source: A.I.D.

1. High-potential zone, unimodal rainfall pattern (1,000 to 2,200 mm), 1,600 to 2,300 m altitude
2. Medium-potential zone, bimodal rainfall pattern (700 to 1,800 mm), 1,000 to 1,700 m altitude
3. Low-potential zone, scanty, short-duration rains
4. Coastal strip, hot, humid belt, some saline soils

During the 1950s, local maize landraces—tracing to probable affinities with Tuxpeño-Hickory King taken to southern Africa in the 19th century, then selected over generations for adaptation as the crop slowly moved north—were gathered from farmers' fields. These materials were used to develop composite populations to form the basic breeding stocks. However, because the germplasm base had been markedly narrowed through selection, efforts to improve this material met with little success, and local breeders looked for new sources of genetic diversity.

In the late 1950s, new exotic germplasm, notably Ecuador 573 and Costa Rica 76, was introduced into the breeding stocks, and a search began for maizes with heterosis in crosses with local strains. During the 1960s, inbreeding and hybridization with local materials were carried out and the first hybrids were released. Several improved varieties and conventional hybrids were made available to farmers: Kitale II and hybrids H 631, H 621, and H 622. Also, a variety cross H 611 (KII x Ecu 573) was released for commercial use.

A maize breeding program was undertaken at Kitale, Kenya, as part of the U.S. cooperation with the East African Agriculture and Forestry Research Organization (EAAFRO). To strengthen this cereal improvement research, the U.S. Agency for International Development and the U.S. Department of Agriculture agreed in 1963 to cooperate in a Major Cereals Project in Africa, which included Kenya (Eberhart and Sprague 1973; Johnson et al. 1980). The USAID-USDA Program set up a comprehensive breeding system using two composites (Comp. B and Comp. R) which were improved by recurrent selection.

Since 1963, more than a dozen open-pollinated varieties and composites and various types of hybrids have been released for commercial production (table 2). Hybrid maize has become so popular in Kenya that most farmers in the more favored production areas will

Table 2. Maize varieties released by Kenyan National Breeding Programs

Variety[a]	Type[b]	Year of release	Yield (% of KSM)
KSM	OP	-	100
ECU 573	OP	1959	-
KS II	OP	1961	107
H 611	VC	1964	142
H 621	DC	1964	132
H 631	TWC	1964	140
H 622	DC	1965	135
H 632	TWC	1965	140
H 612	TC	1966	155
KCB	OP	1967	-
H 511	VC	1967	-
H 512	VC	1970	-
H 611C	VC	1971	155
H 613	TC	1972	166
CMC	OP	1974	-
H 614	TC	1976	166
H625	DC	1981	176

Source: Ochieng 1985

[a]KCB = Katumaini Composite B; CMC = Coastal Maize Composite;

[b]OP = open-pollinated variety; VC = variety cross; DC = double-cross hybrid; TWC = three- way cross hybrid; TC = top-cross hybrid

not accept anything else. Between 1963 and 1981, the hybrid area has increased from zero to nearly 600,000 ha. Until the late 1960s, large-scale farmers dominated the use of hybrids; since then, the number of small-scale farmers has increased greatly.

Maize materials from both CIMMYT and IITA continue to be evaluated by national maize program scientists. Some have been used for the development of several experimental hybrids yet to be released. Although CIMMYT populations and pools are generally susceptible to common rust and turcicum blight, some are being used in the breeding program. CIMMYT Populations 21 (Tuxpeño-1), 49 (Blanco Dentado-2), and 32 (ETO Blanco) have been used in the development of several varietal hybrids in Kenya: PWAN-1, H-1, H-2, and H-3.

A good streak virus tolerant composite (TZSR) from IITA has been included in the B population in Kenya. Streak-resistant inbred lines for both lowland and mid-altitude environments have been supplied by IITA (personal communication, S.K. Kim). Breeding materials from the CIMMYT/University of Zimbabwe collaborative mid-altitude breeding program are also being supplied from Harare.

The Kenya Seed Company (KSC), in which the Government of Kenya now has 51% ownership, has a monopoly on seed production in the country and also exports seed (hybrids) to neighboring countries. Maize seed constitutes its largest crop, with a volume in 1984 of 14,000 t. In 1985-86, the KSC produced 10 hybrids and 2 open-pollinated varieties for the various agroclimatic areas of the country. Breeder seed for these varieties comes from three agricultural research stations and from KSC's small but effective maize research program. Most farmers in the high potential areas use improved seed. In marginal regions, landraces are still often found.

Lesotho

Maize is the staple food in Lesotho. In 1983, 90,000 t of grain were produced on 60,000 ha, with national yield averaging 1.5 t/ha. Lesotho is entirely surrounded by South Africa. Maize growing areas can be divided into three major agroecological zones: the lowlands, the foothills, and the Maloti mountain range, where land is cultivated as high as 3,000 m elevation.

Maize research is carried out by Agricultural Research Lesotho (Ntlhabo and Matli 1985). For the low elevations, South African hybrids are the dominant materials grown. In the more mountainous regions, because of the shorter growing season and cooler conditions and the subsistence nature of maize production, open-pollinated varieties are more suitable genotypes. CIMMYT is collaborating with Lesotho researchers to develop high-yielding varieties for the highland areas. Pools 1, 2, and 4 supplied by CIMMYT markedly outyield the two best South African hybrids, SA4 and SA11, in this zone. Seeds from these materials have been multiplied and are being tested extensively through on-farm trials. CIMMYT reports that Pools 1 and 4 have been released as open-pollinated varieties and are under commercial production.

Malawi

Maize is the principal staple food in Malawi. During 1983-85, approximately 1.4 million t of grain were produced annually on 1.2 million ha, with national yields averaging 1.2 t/ha. In recent years, Malawi has been a net maize exporter. Maize is grown by small-scale farmers for food and cash and by large-scale farmers

Table 3. Seed produced by the National Seed Company of Malawi, 1978-79 to 1983-84, in tons

Material	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84
MH 12 (single cross)	911	1,143	2,123	1,704	1,617	3,015
MH 13 (3-way cross)	37	166	—	—	—	—
NSCM 41 (3-way cross)	—	—	—	9	236	574
UCA Basic (composite)	6	—	—	—	—	—
UCA (certified)	201	515	2,231	153	135	333
CCA Basic (composite)	7	—	—	—	—	70
CCA Certified	90	35	44	55	110	53
A 73N (inbred line)	42	—	19	52	57	1
B 76S (inbred line)	—	—	8	5	—	—

Source: National Seed Company of Malawi

mainly for commercial purposes. There has been a remarkable increase in the area grown with maize over the past five years, though not in yields.

About one-quarter of the maize area in Malawi is planted with improved materials: 17% with improved open-pollinated maize (composites) and 9% with hybrids (personal communication, A. Manwiller). The local unimproved varieties are mostly flints to semi-flints, which are preferred because of their resistance to stored-grain insect attack and because of their flour-making qualities. Initially, maize breeders were using dents in their improvement programs. CIMMYT has supplied improved flint germplasm, and these materials are being used in crosses with Malawian dents. Hybrid maize is grown only for commercial purposes where industrial millers sell meal mainly to the urban population.

Maize improvement work in Malawi is focused on production problems in two ecological zones: (a) high potential areas where rainfall is not a limiting factor (more than 600 mm) to successful maize growth and (b) marginal areas where rainfall (less than 600 mm) is a limiting factor (Ngwira and Sibale 1985). The program for marginal areas is evaluating materials with earlier maturity from CIMMYT, IITA, and South Africa. The materials obtained from South Africa are mainly inbred lines that perform better than materials from other regions of the world in terms of disease and adaptability. A number of the newly released hybrids in Malawi, mostly single-cross hybrids, have been derived from these lines.

CIMMYT materials—especially white flints—have served the national program in two ways: (a) for direct or indirect use in the formation of open-pollinated varieties for the small-scale farmer and (b) to form new source populations. An open-pollinated variety, Chitedze composite C, was released in 1976. This composite was formed by crossing 36 entries selected on the basis of their visual performance in two CIMMYT variety trials, EVT 12 and ELVT 18, consisting mostly of late tropical materials of variable kernel types. Tuxpeño 1 (Pop. 21) was also identified from the CIMMYT experimental varieties as being well adapted to the northern lakeshore area of Malawi. This variety was released in 1985 under the same name.

Since 1981, the Malawi Improvement Program has been cooperating with IITA. It has received streak-resistant materials that have been incorporated into national breeding populations for evaluation under local conditions of natural infection. Inbred lines are being extracted from one population, TZESR, which is moderately resistant to streak virus attack. IITA inbred lines and hybrids have also been supplied to maize researchers at the Chitedze Station (personal communication, S.K. Kim).

The National Seed Company of Malawi (NSCM), established in 1976, multiplies the seed of improved materials by contract with commercial farmers. Seed of both hybrids and open-pollinated varieties has been produced (table 3).

At present, NSCM is handling two hybrids: MH12, a single-cross hybrid, and NSCM 41, a three-way cross hybrid. Parent seed for two newly released hybrids was handed over to the company in 1984, and production of the new hybrids was planned to commence in the 1985-86 cropping season. NSCM also produces seed of composite varieties. At present, it is producing Ukirigula Composite A (UCA) and Chitedze Composite A (CCA). Tuxpeño 1 will shortly be added to the list of open-pollinated maize seed multiplied by the company.

Mozambique

Maize is the main staple food of most Mozambicans and is grown throughout the country. During 1983-85, 333,000 t of grain were produced annually on 600,000 ha, with national yields—the lowest in sub-Saharan Africa—averaging 0.6 t/ha. Disease problems (mainly downy mildew and maize streak virus), insect pests, weeds, and lack of water are all serious biological constraints in one or more of the three major agroecological zones in which maize is grown.

Maize research is carried out by the National Agricultural Research Institute (INIA), which initiated the national maize research program after independence in 1977 (Nunes and Satarie 1985). In recent years, social and political upheavals have seriously affected maize research efforts, and many valuable materials have been lost.

Several open-pollinated varieties based on CIMMYT materials have been selected for release. Foundation seed has been produced for five experimental varieties: Obregon 7643, Cotaxla 7921, and Ferke 7822 for high altitudes; and San Andres 7823 and Mexico 8049 for the northern lowlands. Streak resistant materials from IITA have also been obtained and are being used in the breeding program; a variety based on TZESR-W has been selected for commercial release (personal communication, S.K. Kim). Through technical assistance from the Yugoslavian Maize Institute, a hybrid development program was started in 1984.

Three national institutions are involved in maize seed production: INIA is responsible for producing breeders' and basic seed; the National Seed Company (ENS) is responsible for certified seed production; and the National Seed Service (SNC) is charged with quality control.

Reunion

The Department Cultures Vivrieres Du Cirad cooperates with IITA and CIMMYT in germplasm exchange and testing (Marchand and Hainzelin 1985). The breeding program is devoting major efforts to the study of four viruses: maize streak virus, maize mosaic virus, maize stripe virus, and sugar cane mosaic virus. Since vector insects are important in virus transmission in maize the entomological aspects of these diseases are also under study. IITA's streak-resistant materials are also being utilized. IITA's inbred lines are also used to test strain variations of maize streak virus (personal communication, S.K. Kim). Tocumen (1) 7931, selected from CIMMYT material in 1984, is being increased despite susceptibility to *H. turcicum*. Most farmers grow open-pollinated varieties, but one hybrid, IRAT 143, has had some success.

Seed production in Reunion is very limited and not well organized. Scattered private institutions produce seed but there is no organized agency. In 1985, improved seed of the following genotypes was produced (Marchand and Hainzelin 1985): Revolution (local improved variety), 5 t; IRAT 143 (hybrid), 1 t; and Tocumen (1) 7931, 5 t.

South Africa

Maize is the major staple for most of the country's people. During 1983-85, approximately 5.3 million t of grain were produced on 4.1 million ha, with national yields averaging 1.3 t/ha. During 1982 and 1983, severe drought reduced national production: viz, 13 million t in 1980 and 4 million t in 1982. In most years, however, South Africa is an important maize exporter.

Almost all of the South African maize area is planted with hybrids—three-way and four-way crosses (personal communication, Mike Barrow). Most of these hybrids are based on material from the United States that was introduced during the early part of this century (personal communication, D. Duvick). There are no public sector seed companies handling maize seed. Seven private companies are active in South Africa. Materials from CIMMYT and IITA have not been well adapted, but they are screened for disease resistance and for resistance/tolerance to African Maize Stalk borer, *Busseola fusca*. The Pioneer Seed Company (Pty) Limited (no association with Pioneer Hi-Bred International Co. of the United States) has received open-pollinated populations from both IITA and CIMMYT. Inbred lines are being developed from the most promising materials (80% to 85% of effort), and population improvement makes up the remainder of the breeding program.

Figure 8. CIMMYT maize trainee from Africa. Source: CIMMYT.

SOMALIA

Maize is the second most important crop in Somalia, after sorghum. During 1983-85, approximately 130,000 t of grain were produced annually on 138,000 ha, with national yields averaging 0.9 t/ha.

Maize research began in 1977 and is carried out by the Central Agricultural Research Station (CARS) at Afgoi (Abbanur 1985). In 1979, the variety Afgoi Composite was developed from Somali landraces, Guatemala Flint, and U.S. hybrids. Another variety, Somtux, was developed in 1980 from half-sib crosses between Afgoi Composite and Tuxpeño (obtained from Tanzania). Somtux is a white, semi-dent grain, full-season variety. Because of discontinuity in the breeding programs, both varieties have lost their genetic purity and have become contaminated.

The Somali maize program's germplasm improvement priorities are to develop high-yielding varieties with tolerance to drought and resistance to the stem borer *Chilo partellus*. CIMMYT, IITA, and the Semi-Arid Food Grains Research and Development project (SAFGRAD) are cooperating with CARS in these breeding efforts. Nearly 200 experimental varieties supplied by CIMMYT have been evaluated in field trials since 1981. Promising materials include Across 8121, Across 8149, Los Diamantes 7823, Across 7822, Pirsabak 7930 (early maturing) and Poza Rica 7926. The best performing materials from the SAFGRAD trials have been Pool 16 (early maturing) and TZPB. Pirsabak 7930 and Pool 16 are being crossed with the F_1 progeny of the locally developed variety-cross hybrid, ISOMA, in order to introduce greater earliness into this material.

SWAZILAND

Maize is the principal staple in Swaziland. Approximately 90,000 t of grain were produced annually in 1983-85 on 60,000 ha, with national yields averaging 1.5 t/ha. Maize production has been cyclic depending on climatic conditions in recent years.

Approximately 80% of the land is planted with hybrids, with the balance planted with local open-pollinated materials or second-generation hybrid seed (Shikhulu and Mavimbela 1985). The main hybrids in use are SR 52 (from Zimbabwe) and NPP x K64R (from South Africa). Seed of hybrid maize is produced and distributed by a national agency, the Swaziland Seed Multiplication Project. Several private companies and cooperatives also distribute maize seed.

Inbred lines and varieties with maize streak virus resistance are received from IITA. The program also receives open-pollinated varieties from CIMMYT that are evaluated for yield and general adaptation. One such variety, Across 7443, is now commercially available. Several more varieties—based on CIMMYT Populations 22 (Mezcla Tropical Blanca), 23 (Blanco Cristalino-1), 24 (Antigua-Veracruz 181), and 47 (Templado Blanco Dentado-2)—have been selected for further testing and possible eventual release.

TANZANIA

Maize is the most important food crop in Tanzania. In 1983-85, approximately 1.6 million t of grain were produced annually on 1.5 million ha, with national yields averaging 1.1 t/ha. Most farmers prefer white, flint-type maizes.

Tanzania's National Maize Research Program (NMRP) was established in 1973 with the assistance of IITA, CIMMYT, and USAID. Maize research is focused on three agroecological zones (personal communication, A.J. Moshi): (1) the lowland zone, including coastal and other areas below 900 m elevation, (2) a mid-altitude zone between 900 and 1,500 m but subdivided into two sub-zones: (a) areas with more than 1,100 mm rainfall and with a longer growing season, and (b) areas with less than 1,100 mm rainfall and with a shorter growing season, and (3) the highland zone above 1,500 m elevation—the major production area—which usually receives sufficient rainfall and has relatively long growing seasons. Maize streak virus is a problem in the lowland and mid-altitude zones, and *H. turcicum*, ear rot, and stalk borers can be serious problems in the high-altitude zones.

The breeding program has been involved in improving populations, in the formation and testing of varieties, and in the supplying of national foundation seed farms with breeders' seed of both open-pollinated varieties and inbred lines. A major effort is aimed at formation of open-pollinated varieties for commercial use by farmers. About 10% of the breeding program involves inbred development and hybrids, but this activity is increasing. Beginning in the 1982-83 season, the NMRP began forming top crosses for possible hybrid production and for obtaining information for restructuring the populations on the basis of heterotic patterns.

The NMRP of Tanzania cooperates with various international breeding programs including CIMMYT, IITA, and SAFGRAD (personal communication, A.J. Moshi). International progeny trials are tested for local adaptation; variety trials are received for both open-pollinated and hybrid materials; and seed is requested of varieties, inbreds, and breeding material. The materials are either tested locally or used in breeding and selection for local improvement. Four open-pollinated varieties based on CIMMYT germplasm have been released for commercial production. Materials from IITA are evaluated for streak virus diseases resistance. TZESR-W has shown high resistance to MSV and good yield potential in national trials (personal communication, S.K. Kim). None of the IITA material has been released, but some of the streak resistant converted materials and newly tested hybrids are promising.

Presently, two hybrids, H 6302 and H 614, developed by the East African Agriculture and Forestry Research Organization (EAAFRO), are recommended for the high-elevation, long-season areas of the southern highlands. The hybrids, H 632 and H 622, and the open-pollinated variety, UCA, are recommended for the intermediate-elevation areas. For several years, Illonga Composite has been recommended for areas below 900 m elevation. The full-season variety, Tuxpeño (Population 21, Tuxpeño-1) is grown on a limited scale in the northeastern and southern lowlands. Until recently the variety Katumani was the only early-maturing material available. In 1983, the NMRP released a new early-maturing variety, Kito (Population 30, Blanco Cristalino-2), for areas below 1,300 m elevation and two full-season varieties, Kilima (Pop. 21) and Staha (Pop. 21), for the intermediate and low-altitude zones, respectively.

Table 4. Seed production of improved maize genotypes in Tanzania, 1972-73 to 1983-84, in tons

Season	Hybrids	Open-pollinated varieties	Total
1972-73	420	1	421
1973-74	666	109	775
1974-75	1,366	1,050	2,416
1975-76	1,484	1,638	3,122
1976-77	916	2,128	3,044
1977-78	409	1,061	1,470
1978-79	2,485	1,615	4,100
1979-80	3,022	107	3,129
1980-81	2,129	1,516	3,645
1981-82	1,525	851	2,376
1982-83	1,909	1,465	3,374
1983-84	2,537	1,114	3,651

Source: Personal communication, A.J. Moshi.

Improved variety and hybrid breeder's seed is increased to foundation seed at national foundation seed farms. The Tanzania Seed Company, established in 1973, contracts with institutions and larger scale farmers to produce certified seed. The latter is marketed solely by the Tanzania Seed Company. There is no private maize seed company. The use of improved seed has increased significantly since 1973 (table 4). Even so, many farmers still do not buy certified seed because of cost factors, delivery problems, and a lack of knowledge about the importance of using quality seed.

UGANDA

Maize is an important staple in Uganda. During 1983-85, approximately 365,000 t of grain were produced annually on 358,000 ha, with national yields averaging 1.2 t/ha.

The Ugandan maize program has been destroyed by internal war and must be rebuilt. Cooperation with IITA and CIMMYT will be very important in supplying populations and inbred lines (personal communication, Oguti W. Mangheni). IITA has supplied streak-resistant material for the lowland areas and has been assisting in converting local varieties to streak resistance. The Ugandan maize program is also interested in releasing varieties from CIMMYT Populations 21 (Tuxpeño-1), 22 (Mezcla Tropical Blanca, 43 (La Posta), and 49 (Blanco Dentado-2) (Kaahwa and Kabeere 1985).

The most popular improved open-pollinated varieties in Uganda are Kawanda Composite A and Katumani, a Kenyan variety used in the semi-arid Karamoja region. Some hybrid seed is also imported from Kenya, mainly H 622, H 632, and H 614. The Uganda Seed Project (USP) is responsible for the production of improved seed, which is marketed by farmers' cooperatives as well as by the USP. The Karamoja Seed Scheme also produces improved seed for farmers in that region.

ZAMBIA

Maize is the most important crop in Zambia. It is grown in most regions of the country, except in exceptionally dry, wet, or infertile areas where sorghum, millet, or cassava are better adapted. During 1983-85, approximately 863,000 t of grain were produced annually on 512,000 ha, with national yields averaging 1.7 t/ha, among the highest in sub-Saharan Africa.

Hybrids dominate commercial production areas, and open-pollinated varieties dominate subsistence agriculture areas. Approximately 30% of the total maize area is planted with hybrids and 15% with improved open-pollinated varieties and composites (Chibasa 1985). Maize streak virus can cause serious economic losses in certain years (personal communication, S.K. Kim).

CIMMYT and IITA collaborate with Zambian maize researchers, and international trials from both IARCs are regularly received and grown. Two open-pollinated varieties based on CIMMYT germplasm have been released by the national program. Since 1980, scientists in a joint Zambia/FAO research project have screened over 200 streak-resistant lines in a national hybrid development program. A collaborative Zambian/Yugoslavian maize program has also used IITA lines for hybrid development. IITA's streak-resistant mid-altitude population (TZMSR-W) and several of the CIMMYT/IITA streak-resistant conversions of experimental varieties show promise in Zambia (personal communication, S.K. Kim).

The Zambia Seed Company (Zamseed) has been responsible for the production, procurement, and distribution of maize seed. The seed is produced by farmers in the Zambian Seed Producers Association, and quality control is conducted by the Seed Control and Certification Institute. The main hybrid in use is SR 52 (single-cross) which was developed in Zimbabwe. In 1983, an improved version of SR 52, named MM 752, was released and has shown great promise. In 1984, seven other hybrids were released: MM 501, MM 504, MM 602, MM 603, MM 604, and MM 606. In addition, two open-pollinated varieties based on CIMMYT materials, MMV 400 (Pirsabak (2) 7930, Pop. 30, Blanco Cristalino-1) and MMV 600 (Pop. 21, Tuxpeño-1), were also released and are being extensively grown. These new cultivars provide Zambian maize producers with the needed flexibility to adjust planting dates according to the onset and duration of the rainy season (Chibasa 1985).

ZIMBABWE

Maize is the principal staple in Zimbabwe. During 1983-85, approximately 1.7 million t of grain were produced annually on 1.3 million ha, with national yields averaging 1.2 t/ha. Both total production and yields during this 2-year period were 25% below average due to severe drought. In most years, Zimbabwe is a net maize exporter.

Zimbabwe's maize breeding program was started in 1932 and is one of the oldest in Africa. The initial genotypes developed were open-pollinated varieties. In 1950, Southern Cross was the dominant variety grown in the country. Since then, 14 double, 5 three-way, 6 single, and 6 modified single-cross hybrids have been released (personal communication, R.C. Olver). The single-cross hybrid, SR 52, released in 1960, replaced SR 14 because it was higher yielding. For more than two decades, SR 52 has continued to be the dominant hybrid in Zimbabwe (grown on 85% of hybrid area) and is also widely grown in other African countries (Billing 1985). Two shorter season hybrids, R 200 and R 201, are grown on the remaining 15% of the hybrid maize area. R 201 has tended to replace R 200, which is susceptible to weevil damage (Billing 1985).

Figure 9. Pounding maize to make corn meal for home use, Africa. Source: CIMMYT.

The Zimbabwe maize breeding program cooperates with IITA and CIMMYT. This collaboration was strengthened substantially with the establishment of a joint mid-altitude breeding station in cooperation with the University of Zimbabwe. The station was established jointly by CIMMYT and IITA in 1985 and operated for 2 years under joint sponsorship. IITA has recently withdrawn from formal involvement as part of a new agreement with CIMMYT concerning regional division of responsibility (IITA for western and central Africa, and CIMMYT for eastern and southern Africa). But IITA will continue to be informally involved and cooperate with CIMMYT.

The greatest contribution from the IARCs has been the identification of streak virus resistant germplasm and the incorporation of this into different local populations. IITA's mid-altitude population, TZMSR-W—and the inbreds and hybrids derived from it—have shown high resistance to MSV and *H. turcicum* (personal communication, S.K. Kim). CIMMYT's international progeny and variety trials are routinely evaluated; Population 48 is also being used to reduce plant height in various national materials. Relatively small proportions of CIMMYT and IITA germplasm have been introgressed into a few of the 28 locally constituted populations, which are undergoing various forms of recurrent selection to serve as long-term genetic sources of new inbred lines. None of the released hybrids have any germplasm from either CIMMYT or IITA.

The Seed Co-op Company of Zimbabwe, a cooperative of commercial farmers, has the sole right to market government-developed hybrids. All commercial farmers grow hybrids and at least 70% of the communal peasant farmers also grow hybrids (Billing 1985). The commercial farmers grow about 250,000 ha of maize and the communal farmers plant about 1,000,000 ha. Commercial yields generally average 5 to 6 t/ha while the communal group yields average between 1 and 2 t/ha. Since Independence, the Zimbabwe Government has given priority to increasing yields among the communal farmers: considerable headway in transferring improved varieties and production technologies has been made during the 1980s.

Western and Central Africa

Benin

Maize is the major food staple in Benin. During 1983-85, approximately 370,000 t of grain were produced annually on 485,000 ha, with national yields averaging 0.7 t/ha.

The national maize program cooperates with CIMMYT, IITA, and SAFGRAD. The variety TZB received from IITA is grown in the northern region; an experimental variety from TZSR-W-1 is also being extensively used in on-farm testing. Kpatcha-Kpatcha (Poza Rica 7843-SR) and Pirsabak (Pirsabak (1) 7930-SR) from the CIMMYT/IITA joint program have been introduced into the southern region.

Burkina Faso

Maize is the third most important cereal grain, after millet and sorghum. During 1983-85, approximately 90,000 t of grain were produced annually on 128,000 ha, with national yields averaging 0.7 t/ha.

The national maize program cooperates with CIMMYT, IITA, and SAFGRAD, which is headquartered in Burkina Faso. Safita-2, derived from CIMMYT Pool 16, has been released. In addition, a streak-resistant version derived from CIMMYT Population 21 (Tuxpeño-1) is being considered for release in the southern areas. The Burkina Faso/IRAT maize program selected two IITA hybrids, 8322-13, and 8428-19 in 1985 for commercial release (personal communication, S.K. Kim)

Cameroon

Maize is the major food staple in Cameroon. During 1983-85, approximately 510,000 t of grain were produced annually on 443,000 ha, with national yields averaging 1.2 t/ha.

The national maize program cooperates with IITA and CIMMYT. IITA currently has resident maize staff stationed in the country as part of the USAID-supported National Cereals and Extension Project. The IITA staff posted in Cameroon focus their work on varietal improvement for lowland, mid-altitude, and highland ecologies. In view of the importance of maize streak virus in the lowland areas, only streak-resistant varieties are being released. Several streak-resistant varieties based on IITA populations and the CIMMYT/IITA conversion program have been released: TZB and TZPB are currently grown on approximately 10,000 ha. Since 1984, IITA hybrids have been tested extensively; some of these hybrids are showing tolerance to *Striga* (personal communication, S.K. Kim).

Central African Republic

Maize is an important food crop in the Central African Republic. In 1983, approximately 30,000 t of grain were produced annually on 100,000 ha, with the average national yield equal to 0.3 t/ha, the lowest in sub-Saharan Africa.

Tuxpeño-1 was introduced in the early 1980s and is being used. International variety trials were supplied by CIMMYT in 1983 and 1984 to research stations in Soumbe and N'Goulinga; the best varieties in these trials had yields 60% above the local checks (personal communication, M. Bjarnason). Particularly promising are varieties from Populations 22, 32, and 43.

Côte d'Ivoire

Maize has become a very important staple food for most of the population of Côte d'Ivoire. During 1983-85, approximately 478,000 t of grain were produced annually on 575,000 ha, with national yields averaging 0.8 t/ha. Both yellow and white flour is used, depending on tribal customs. The grain is used as human food in diverse forms. Recently, more maize is being used as animal feed.

The Côte d'Ivoire national maize program has been developing both improved populations and inbred lines for a hybrid program (personal communication, H. Dosso). Improved germplasm from CIMMYT has been extensively used since 1975 and 20 experimental varieties have been developed. Tuxpeño P.B. is widely grown in the country. The CIMMYT/IITA material converted to streak virus resistant populations, e.g. EV 8428-SR and EV 8435-SR, has also been used extensively. The program requests promising experimental varieties from both IARCs to use as varieties per se or germplasm for their breeding program. The Pioneer Hi-Bred International program in Côte d'Ivoire is using IITA's streak-resistant lines and has identified a superior hybrid combination between an IITA inbred line and an inbred line from Pioneer's maize program in Thailand (personal communication, S.K. Kim). The designation "FERKE" is used on experimental varieties, but is changed to "IDSA" when released.

In the past, seed production and distribution has been the responsibility of the state seed company, BETPA. Recently the Government has provided additional funds to the Ministry of Rural Development to improve public-sector seed production and distribution systems. BETPA has switched from the local land variety CJB to IDSA 29 (Ferke 7928, Pop. 28 Amarillo Dentado) for a late variety and IDSA 28 (Ferke 7635, Pop. 35, Antigua-Rep. Dominicana) for an early variety (IDESSA 1984). Other varieties that have been released by the national program and include CIMMYT germplasm are IDSA 26 (Ferke 7529, Pop. 29, Tuxpeño Caribe), IDSA 27 (Ferke 7622, Pop. 22, Mezcla Tropical Blanca), and IRAT 81 (a variety hybrid whose female parent is Tuxpeño brachytic).

GAMBIA

Maize is not a significant crop in Gambia. The area planted with maize is 5,000 ha, though the total is growing. Only improved open-pollinated varieties are planted (personal communication A.G. Carson). The Ministry of Agriculture cooperates with CIMMYT—testing early maturing varieties—and with IITA, testing early, streak virus, and *Striga* (witchweed) resistant varieties. Research is aimed at improved open-pollinated varieties. Cooperation with the IARCs has been good.

The Government's Seed Multiplication Unit distributes some seed of improved open-pollinated varieties.

GHANA

Maize is the major food staple in Ghana. During 1983-85, approximately 402,000 t of grain were produced annually on 418,000 ha, with national yields averaging 1.0 t/ha. Small-scale farmers account for 90% of national production. The majority of maize is intercropped, primarily with cassava and cocoyam in southern Ghana and with sorghum, millet, groundnuts, and cowpeas in the Guinea savannah.

The Ghana Grains Development Project (GGDP) was launched in 1979 with the objective of making Ghana self-sufficient in maize production (GGDP 1986). As of 1987 CIMMYT had two maize scientists and IITA had one cowpea scientist assigned to this project. Objectives of the GGDP maize breeding program are to develop the following maize materials:

1. 120-day white dent varieties for the forest and transition zones in the major rainy season. These meet about 60% of the national varietal requirement.

2. 105-day, white dent varieties for the minor rainy season in the forest and transition zone. These meet about 20% of the national varietal requirement.

3. 90-day, yellow flint varieties for early planting in the Guinea savannah. These meet about 5% of the national varietal requirement.

4. 90-day soft white dent varieties for use in the Coastal and Guinea savannas. These meet about 5% of the national varietal requirement.

5. 100-day yellow dent varieties for use throughout Ghana. These account for about 10% of the national varietal requirement.

To date, three improved varieties, La Posta, Composite 4, and Golden Crystal—all full-season white dents derived from CIMMYT material—are widely grown. In addition, an earlier (105-day) white dent, Safita 2 (based on CIMMYT's Pool 16), has been released for use during the minor rainy season in the forest and transition zone. Improved open-pollinated varieties are used on a substantial portion of the total maize area, and the three above-mentioned full-season varieties are grown on 25% to 30% of the total national maize area. Recently, two new varieties based on CIMMYT germplasm have been released: Dobidi CRI 1, derived from Ejira (1) 7843, and Aburotia CRI 1, derived from Tuxpeño P.B. C_{16}. Even though not officially released, IITA supplied, upon request, 2 t of TZESR-W to the Ghana Seed Company in 1983 for seed multiplication and distribution in the Volta region.

LIBERIA

Maize is grown on only about 15,000 ha nationally (personal communication, Cyril E. Broderick). The national maize program receives open-pollinated varieties, full-sib progeny, and various disease-resistant high yielding hybrids from IITA. It started receiving variety trials from CIMMYT in 1982, and varieties from Populations 21, 23, 28, and 43 have performed well. In addition to testing these materials for local adaption, some selection is being done locally. The Central Agricultural Research Institute (CARI) is making some crosses.

Most of the breeding program is aimed at improved open-pollinated varieties. Only a very limited amount of effort is used in inbred line development. At present, no releases of improved varieties have been made, though they do have several promising lines. Hybrids are very rare and would make up less than 1% of plantings. Maize production has been increasing at

Figure 10. Dr. S.K. Kim, IITA maize breeder, discusses hybrid breeding work at a government arranged field day in Lagos state, Nigeria, in 1985. Source: IITA.

a rate of 2% to 4% per year. Seed production is a major bottleneck to increased production. There is no national seed production, but a few private companies import seed.

Nigeria

Maize is an important crop in Nigeria. During 1983-85, approximately 2.1 million t of grain were produced annually on 2 million ha, with national yields averaging 1.0 t/ha.

Maize improvement under the auspices of IITA began with the formation and improvement of two populations: TZB, which originated from both African and Latin American sources, with Nigerian Composite B most important; and TZPB, which is derived from Tuxpeño Planta Baja Cycle 7 from CIMMYT (personal communication, Y. Efron). These two were released by the Nigerian National Program as FARZ 27 (TZPB) and FARZ 34 (TZB). Both varieties are full season and have good resistance to tropical rust (*Puccinia polysora*) and lowland blight (*Helminthosporium maydis*).

The National Accelerated Food Production Program (NAFPP) in Nigeria conducted a total of 10,217 mini-kit trials in 15 states between 1974 and 1978. NAFPP distributed 728 t of seed of these two varieties to local farmers (1975 to 1978). Results of the mini-kit trials showed an average 30% increase in yield compared to local farmers' variety. It is estimated that these two varieties are grown on about 1 million ha in Nigeria.

More recently, streak-resistant variety conversions from CIMMYT Populations 28 (La Maquina 7928) and 43 (Poza Rica 7843) have been released and are being multiplied by the National Seed Service. Seed multiplication of three additional new varieties has also been recently initiated: TZMSR-W for the mid-altitude ecology of Plateau State (combined MSV, *H. turcicum* and *P sorhi* resistance) and DMRLSR-W and DMRESR-W (combined MSV and downy mildew resistance) for the maize areas affected with these diseases in Ondo, Bendel, and Kwara States.

A joint IITA-Nigeria program was—as noted previously in the IITA portion of chapter 2—initiated in 1982. In 1984, IITA maize hybrids were tested in on-farm demonstrations (a total of 150 ha) across Nigeria. These plantings were made by Nigerian farmers with the cooperation of both the Nigerian National Research and Extension Organizations and the support of the Federal Government of Nigeria. Selected hybrids produced between 25% to 60% more yield than the check variety, TZSR-W-1. Two private seed companies have been recently formed (with IITA assistance) to produce these hybrids: Agricultural Seeds Nigeria and the Limited and Temperance Seed Company. Under the supervision of IITA and the National Seed Service personnel, the two companies produced about 600 t of eight hybrids in 1985 for planting in the 1986 season (personal communication, Y, Efron). In 1986, approximately 1,600 t of hybrid seed were produced, enough to plant 90,000 to 100,000 ha.

Senegal

Maize is becoming an increasingly important crop in Senegal. During 1983-85, approximately 101,000 t were produced annually on 84,000 ha, with national yields averaging 1.2 t/ha. During the past 5 years, maize production has doubled. The Senegalese government objective is to attain self-sufficiency (400,000 t) by 1989.

The Institut Senegalais De Recherches Agricoles receives material from both CIMMYT and IITA (personal communication, Papa Assau Camara). The tropical material tested is selected for early maturing types (90 days, not to exceed 110-120 days). A unique rainy season of 3 to 4 months limits growing of a full-season crop in Senegal. White flinty grain maize is preferred for human food, but some yellow and semi-dent types are used by industries.

The local program created a synthetic variety using material from IITA for adaption to African conditions and unrelated genetic material from CIMMYT to select for high combining performance with the IITA material. Some CIMMYT materials have been distributed to farmers after local selection. They include Camasa 1, based on Tocumen (1) 7835 from CIMMYT, and two quality protein maize varieties based on Obregon 7740 and Temperate White QPM, also from CIMMYT.

National germplasm development emphasizes open-pollinated varieties. They have three levels of selections based on the level of farmer's technology for the intended use of the developed variety. One is the creation of varietal hybrids from crosses of composites—usually between one local variety and an introduced material. To obtain the best specific plants, reciprocal recurrent selection techniques are used. These hybrids are intended for farmers having a high technology for maize production. The second level is the creation of synthetic varieties and composites obtained from full-sib selection. These genotypes are intended for farmers having an intermediate-level technology. The third level is local population improvement by simple recurrent selection methods to develop improved genotypes from local populations for farmers with low technology.

There is a national seed service and a bilateral project with West Germany to promote maize production. The research stations furnish foundation seeds to the national seed service-German project, and they in turn contract with farmers to produce seed. The cooperative project buys the seed and distributes it to the rural extension agencies, which sell directly to their farmers. The maize improvement program recommends the following:

Hybrids:	BOS 111, HVB-1
Varieties:	Synthetic C, Camara 1, APM1 and APM2, CP75 white and yellow composites
Local population:	ZM10 (eastern Senegal)

Source: Personal communication, Papa Assau Camara.

SIERRA LEONE

Maize is not a major crop in Sierra Leone. During 1983-85, approximately 20,000 t of grain were produced annually on 14,000 ha, with national yields average 1.4 t/ha.

Material for testing is received from both CIMMYT and IITA, and cooperation with these IARCs has been good (personal communication, E.R. Rhodes). Three groups of maize trials are received from both IARCs and these are tested locally. Some work is under way to add local adaptation to the most promising selections. This local research is aimed mostly at developing improved local open-pollinated varieties for farm use. Only 10% of the research is concerned with inbred and hybrid development. Two populations have been released for farmer use: TZSR (yellow) and TZPB (white). All the production is open-pollinated varieties. Maize seed is distributed by the Extension Service and private farmers.

TOGO

Maize is an important food crop in Togo. During 1983-85, approximately 191,000 t of grain were produced annually on 179,000 ha, with national yields averaging 1.1 t/ha.

The national maize program cooperates with both IITA and CIMMYT (personal communication, Wilfried Schwieber). La Posta, originally from CIMMYT, is the most widely grown improved variety in Togo. More recently, two streak-resistant varieties based on CIMMYT/IITA germplasm, Poza Rica 7843-SR and Pirsabak (1) 7930-SR, have been released and are being multiplied by a Federal Republic of Germany (GTZ) project in Sotouboua. Cooperation with IITA involves improved streak resistance in open-pollinated varieties (both white and yellow grained). CIMMYT open-pollinated white and yellow varieties are also being tested. Some research to develop low-input technologies for the agroforestry zones is also underway. Five open-pollinated varieties have been released to farmers, with four based on CIMMYT germplasm. Ferme Semenciere de Sotouboua is the national governmental seed company; approximately 120 t of seed is produced per year.

ZAIRE

Maize is the major cereal grain produced in Zaire. During 1983-85, approximately 709,000 t of grain were produced annually on 822,000 ha, with national yields averaging 0.9 t/ha.

The Programme National Mais has cooperated closely with CIMMYT and IITA for many years (personal communication, Mulamba Ngandu Nyindu). Between 1971 and 1981, CIMMYT had maize staff assigned to work with the national program at Lubumbashi. It receives the full complement of experimental materials available from the Center. IITA populations also have been used in crosses with the local Zairian varieties. Populations TZDMRSR-W, TZDMRSR-Y, TZMSR-W, and TZEMSR-W have shown high levels of resistance to one or more of the following diseases: downy mildew, maize streak virus, and *H. turcicum*. Currently, IITA is involved in a substantial bilateral maize research assistance project, sponsored by USAID, with the national maize program and has several maize scientists stationed in the country.

The national program has released four open-pollinated varieties from the CIMMYT material:

Salongo:	10 best families of Tuxpeño 1, C_{11}
Kasai 1:	Tuxpeño x Eto Blanco
PNM 1.:	(Tuxpeño and Mix Colima grl I and ETO Blanco) x Shaba Safi
Shaba I:	Tuxpeño x Eto Blanco x Shaba Safi

Most Zairian farmers plant open-pollinated varieties. A few imported hybrids are grown in the southern part of Shaba province. A hybrid program has been initiated and inbreds are being developed. No seed organization exists, and access to seed of improved varieties is limited.

NORTH AFRICA AND THE MIDDLE EAST

North Africa

EGYPT

Maize is the major cereal grain produced in Egypt. During 1983-85, approximately 3.6 million t of grain were produced annually on 805,000 ha, with national yields averaging 4.4 t/ha. Virtually all maize is produced under irrigation.

Maize research is carried out by the national maize program, Cairo University, and several private companies. National germplasm improvement priorities are to develop high-yielding hybrids and open-pollinated varieties—white and yellow grain—with resistance to late wilt and stalk rot diseases caused by *Cephalosporium maydis*, to *H. turcicum* leaf blight, and to *Ustilago* maydis (personal communication, W. Haag). The national maize program has had close collaborative links with CIMMYT for two decades, and several CIMMYT maize staff members have been stationed in Egypt during this time period. IITA's inbred lines have been screened by maize researchers in national programs and private companies for resistance to late wilt (personal communication, S.K. Kim).

The major improved varieties in use are:

1. Giza-2, an open-pollinated variety with late-wilt tolerance covering 25% of the total maize area. This variety is based on 50% of American Early Dent (AED), developed locally, and 50% of tropical germplasm (Pop. 21) obtained from CIMMYT in the 1969-70 period.

2. P-514, a Pioneer hybrid.

3. DC-202, an AED x Tep.-5 hybrid developed by the national program.

4. Kahera-1, a open-pollinated variety developed by Cairo University.

Certified seed production of these materials during 1984 totaled 8,700 t and was distributed as follows: DC-202, 2,800 t; Giza-2, 4,400 t; P-514, 1,000 t; and Kahera-1, 500 t (unpublished report, W. Haag).

The national maize program released several new hybrids during 1983-84, all of which are based on AED x Tep.-5 crosses: DC-204, DC-215 (double crosses); TWC-9 and TWC-10 (3-way crosses) (unpublished report, W. Haag). Inbreeding is being conducted in CIMMYT material in support of national hybrid development efforts. Inbred lines from the following materials had been developed: Tuxpeño C_{17}; Tlaltízapan 7844; Gemmeiza 7421; (Ant. x Rep. Dom) x Corn Belt; Sids 7444; Pop. 45; Tuxpeño x ETO; Tep.5; and La Posta. Sids 7444 continues to be a source of resistance to late wilt and to *H. turcicum*.

MOROCCO

Maize is not a major crop in Morocco. During 1983-85, approximately 267,000 t of grain were produced annually on 405,000 ha, with national yields averaging 0.7 t/ha.

CIMMYT is cooperating with the Moroccan national maize program to develop high-yielding hybrids and open-pollinated varieties appropriate to dryland as well as irrigated conditions. Progress has been made in

Figure 11. Maize researcher discusses improved maize with farmer, Morocco. Source: CIMMYT.

developing improved materials for the irrigated and higher rainfall areas of the north. U.S. germplasm is playing a major role in the development of hybrids for these areas; Pioneer Hi-Bred is active in this work. Little progress has been made to date toward the development of early, drought-tolerant materials for the low-rainfall areas. Some promising materials for these areas currently under evaluation include BS-5 from the United States and Pools 29 and 30 from CIMMYT (personal communication, W. Haag).

Middle East

TURKEY

Maize is less important in Turkey than wheat and barley, though it is becoming increasingly important as a poultry feed. During 1983-85, approximately 1.6 million t of grain were produced annually on 560,000 ha, with national yields averaging 2.9 t/ha.

Maize research began during the 1950s, in collaboration with FAO. Approximately 30 U.S. hybrids were compared with local varieties in multilocational trials. Two double-cross U.S. hybrids, U.S. 13 and Wisconsin 641 AA, showed high yield potential and were released for commercial production. Additional hybrids were developed during the 1950s and 1960s by Turkish maize breeders using local inbreds and lines from the United States.

Because of inadequate production and distribution of hybrid seed, and the subsistence nature of many Turkish maize farmers, especially in the Black Sea area, the Turkish national maize program began to give more emphasis to the development of improved open-pollinated varieties (OPVs). Three gene pools were constituted using local and foreign germplasm: TMP-1, TMP-2, and TMP-3. After making headway in developing OPVs, the Turkish national program renewed its hybrid work in 1980 (personal communication, W. Haag). Some 150 public lines from the United States were obtained for evaluation through assistance from the CIMMYT Regional Maize Specialist stationed in Turkey. From these inbred lines, five hybrids

Table 5. Foreign hybrids registered in Turkey in 1984-85

Company	Name of hybrid
Northrup King (Tohum Islah)	Matador, Mirko, Silco
Pioneer International	P-3360, P-3320, P-3184, P-3183
Lima Grain (Sapek)	LG-42, LG-55, LG-66
Dekalb	XL-72AA, DK-789, DK-I-Peron
Ciba Geigy	G-4524, G-5050
Basagene (Bereket)	610MF, 714MF, 810MF, M-7676, M-8161, M-84
Jacques	Jx-8820, Jx-247, Jx-187A
Stauffer	S-4460, S-5540, S-6920, S-6915
Asgrow	RX-90
Nickerson	Nickerson-702

Source: Wayne Haag, unpublished CIMMYT report, 1985 have been developed: three single crosses (TTM-813, TTM-815, and TTM-815), one three-way cross (TUM-827), and one double cross (TCM-811). Parent lines all relate to U.S. public lines derived from Lancaster x Stiff Stalk Synthetic.

Since 1984, many private seed companies with international operations have established maize seed production programs in Turkey and have registered a number of "foreign" hybrids for commercial sale (table 5).

With the growth in the private maize seed sector, the role of the national maize program is being reviewed. While still under discussion, it appears that public sector maize research will concentrate on developing OPVs and improved production practices for the Black Sea area (personal communication, E. Kinace). Important maize improvement objectives include the development of high-yielding hybrids and open-pollinated varieties with resistance to *Fusarium* stalk rot and *H. turcicum* leaf blight and to two stalk borers, *Ostringa nubilalis* and *Sesamia cretica*.

The major open-pollinated varieties in use are: Karadeniz Yildizi (K3/74), formed by compositing Yugoslavia hybrids and other germplasm; Ada, formed from CIMMYT Compuesto de Hungaria, Pop. 48; Sapanca, formed by compositing Compuesto de Hungaria and several tropical materials; and Arifye, a late, tall variety used mainly for silage.

ASIA

South Asia

BURMA

Maize is the second most important cereal grown in Burma, and production has been increasing rapidly over the past 15 years. During 1983-85, approximately 317,000 t of grain were produced annually on 185,000 ha, with national yields averaging 1.7 t/ha.

CIMMYT supplies germplasm to the Burmese national maize program (Zin 1986). In particular, the drought tolerance (partially due to more extensive root systems) of certain CIMMYT materials has been especially beneficial. A number of varieties have been released by the national program, with most based on CIMMYT germplasm (table 6).

Table 6. Open-pollinated varieties released by the Burmese National Maize Program and based on CIMMYT germplasm

Name	Grain color	Source material
Shwe-wa 1	Yellow	La Calera (1) 7728 (Pop. 28)
Shwe-wa 2	Yellow	Petrolina 7736 (Pop. 36)
Shwe-wa 3	Yellow	Satipo (1) 7627 (Pop. 27)
Shwe-wa 4	Yellow	Indonesian Early
Shwe-wa 7	White	Tlaltízapan 7322 (Pop 22)
Shwe-wa 8	Yellow	Across 7835 (Pop. 35)
Shwe-wa 9	Yellow	Pichilingue 7931 (Pop. 31)
Shwe-wa 10	Yellow	Fareko 8328 (Pop. 28)
Shwe-wa 11	Yellow	Across 8331 (Pop. 31)

Source: CIMMYT Maize Program

INDIA

Maize ranks fifth in importance among the cereals produced in India, after rice, wheat, sorghum, and millet. During 1983-85, approximately 7.8 million t of grain were produced annually, with national yields averaging 1.3 t/ha.

Indian maize research dates back to the colonial time and to the work of the Imperial Council of Agriculture. After independence in 1947, maize research continued in various states under the auspices of the Indian Council of Agricultural Research (ICAR). A number of inbred lines and double-cross hybrids were developed in Uttar Pradesh and Punjab states, notably Punjab-1, Punjab-2, and Punjab-3; these, however, were not very high yielding.

In 1957 the Indian Government and the Rockefeller Foundation established a joint Coordinated Maize Improvement Programme for India (Mikoshiba 1971). The Rockefeller Foundation assigned several scientists to work with Indian scientists in this new countrywide maize breeding effort and provided financial support and scholarships to strengthen national maize efforts.

One of the first activities of RF and Indian scientists working in the Coordinated Maize Improvement Program was to collect and evaluate exotic germplasms from other countries in order to broaden the germplasm base available in India. Emphasis was on yellow flint grain types. In particular, germplasm complexes from Latin America proved to be useful, including ETO from Colombia, Peru 330, Venezuela 1, Antigua Gr.1 from Antigua via Mexico, and Cuba 342 (Mikoshiba

Table 7. Background of composite maize varieties released in India in 1967

Name	Grain color	Germplasm sources
Amber	Yellow	11 varietal crosses involving five flint varieties (Narino 330, Diacol VI, Venezuela 1, Corneli 54, Eto Amarillo) and six dent varieties (Jarvis, Ferguson, Yellow Dent, Cocker 811 Gr/N 1000/1452, Mexican June, Bolita Amarilla)
Vijay	Yellow	J_1 x Coastal Trop. Flints
Jawahar	Yellow	A_1 x Antigua Gr. 1
Kisan	Yellow	Coastal Tropical Flint
Sona	Yellow	J_1 x Cuba 11J
Vikram	Yellow	Basi x Eto Amarillo

Source: *Maize in India*, Haruo Mikoshiba, 1971.

1971). A large number (more than 4,000) of inbred lines were developed from Indian and foreign germplasms. By 1961, four double-cross hybrids—Ganga 1, Ganga 101, Ranjit, and Deccan—had been released for commercial production.

Although the emphasis in the Coordinated Maize Improvement Program was on hybrid development, population improvement work was also carried out and composite open-pollinated varieties and inter-varietal hybrids were developed. Outstanding among these populations were J-1 (also known as Naraingarh Complex), and Sona (J_1 x Cuba 11J). In 1967, six high-yielding composites—Amber, Vijay, Jawahar, Kisan, Sona, and Vikram—developed from these populations were released for commercial production (table 7).

In addition to national breeding stocks, Indian maize researchers have made considerable use of germplasm from Colombia (ETO germplasm complexes) and southeastern United States (North Carolina and Florida) in developing inbred lines (IARI 1980). While dozens of hybrids have been released, the area planted with hybrids remained stagnant at about 10% to 15% through the 1970s and early 1980s. This situation has begun to change with the expansion of private maize seed sector activities. As of 1986, some 10 private seed companies (transnational and national) are engaged in maize improvement research and seed production in India (Pray 1986). These private sector hybrids are grown on about 10% of the total maize area.

Indian maize researchers participate in CIMMYT's International Maize Testing Program. Perhaps CIMMYT's biggest contribution has been in providing subtropical germplasm for maize varieties and hybrids adapted to production during the winter (Rabi) season (personal communication, R.L. Paliwal). For example, a family of Tuxpeño-1 (Pop. 21) is the female parent in the hybrid, Pathari Makka. India has also released an open-pollinated variety, Lakshami, based on CIMMYT material (Sids 7444, from Pop. 44) grown extensively in Bihar State. A varietal hybrid, Sangam, uses Tuxpeño Planta Baja (C_7) as one parent. Finally, J115-"Parbhat," is based on Suwan 1 from Thailand. Since 1985, IITA has also supplied its inbred lines and hybrids for testing in India.

NEPAL

Maize is the second most important cereal produced in Nepal after rice. During 1983-85, approximately 784,000 t of grain were produced annually, with national yields averaging 1.5 t/ha.

The Nepalese National Maize Development Program (NMDP) receives a broad range of germplasm from CIMMYT (Sharma and Anderson 1985). Most farmers grow open-pollinated varieties, though a few farmers in the south grow Indian hybrids. Three open-pollinated varieties have been released from CIMMYT materials after local selection for better adaptation to Nepalese farming:

1. Janaki (white): (Rampur 7434; Pop. 34)
2. Arun-2 (yellow): (UNCAC x Phil DMR; Pop. 59)
3. Makalu-2 (yellow): (Amarillo del Bajio; Pop. 45)

Of these OPVs, Janaki and Arun-2 have been the most popular with farmers (Sharma and Anderson 1985).

Table 8. Open-pollinated varieties released in Pakistan, 1970-85

Variety	Grain color	Germplasm sources
Changez	White	Swabi white (local) and U.S. inbred lines (WF9, M14, B37, WM13R, HY, A619, Oh45)
Zia	White	(Early King x Payette) x Changez
Khyber	White	Akbar x Bowman's Cole Creek
Shaheen	White	Zia x (Nodak, Mandan, Payette)
Sadaf	White	White version of Neelum
Sarhad White	White	Akbar x Tropical x U.S. Corn Belt
Azam	White	Zia x Pirsabak 7930
Ehsan	White	Sarhad White x Pirsabak 7934
Neelum	Yellow	Local x Latin American x U.S. Corn Belt materials
Agaiti-72	Yellow	Six-way cross (M14 x Pa32) x (WF9 x W9) x (A495 x A556)
Akoar	Yellow	Neelum x U.S. Corn Belt materials
Sharhad Yellow	Yellow	Yellow version of Sarhad
Sultan	Yellow	Akbar x (Syn 548, Syn 547, Neluum and Comp. II)
Sunheri	Yellow	Agaiti-72 x Amarillo Cristalino-2
Kashmir Gold	Yellow	Yousafwala 7845 (Pop.45, Amarillo Bajio)

Source: National Coordinated Maize Programme, Pakistan Agricultural Research Council.

PAKISTAN

Maize is the third most important cereal produced in Pakistan, after wheat and rice. During 1983-85, approximately 1.0 million t of grain were produced on 801,000 ha, with national yields averaging 1.3 t/ha. Most of the maize area is irrigated, and the crop is grown in the hot summer season under very difficult climatic conditions.

Initial maize improvement work in Pakistan focused on hybrid development, relying primarily on inbred lines and hybrids from the U.S. Corn Belt supplied through USAID during the 1950s. In the mid-1960s, the hybrid development work was discontinued due to the lack of a viable seed industry to produce and distribute hybrid seed. Emphasis was placed on developing open-pollinated varieties (synthetics, composites), largely based on temperate germplasm but with some tropical germplasm introgressed for disease resistance to leaf blights (*H. turcicum* and *H. maydis*) and stalk rots caused by *Fusarium* spp. A number of outstanding open-pollinated varieties have been developed, based primarily on U.S. temperate germplasm and some tropical and subtropical materials from CIMMYT (table 8).

CIMMYT and the National Coordinated Maize Program of the Pakistan Agricultural Research Council have had close collaborative research ties for two decades. CIMMYT resident maize advisers have been stationed in Pakistan since 1968, and considerable amounts of CIMMYT germplasm are evaluated annually. Since 1985, national maize researchers have also received IITA's white and yellow grain hybrid trials.

It is estimated that 30% to 40% of the farmers use some kind of mixtures of local varieties and improved genotypes. Among the most extensively grown are Zia, Shaheen, Sarhad, Azam, Akbar, Neelum, and Sultan (Chaudhry 1984). Three open-pollinated varieties based on CIMMYT materials have been released in Pakistan: Azam, Ehsan, and Kashmir Gold (not officially released but widely grown in the States of Azad Jammu and Kashmir).

Figure 12. Maize trial conducted at the Maize and Millets Research Institute, Punjab, Pakistan. Source: CIMMYT.

Provincial and federal maize research programs have reactivated their hybrid development programs in recent years (PARC/CIMMYT 1988). The primary germplasm sources used in these hybrid programs are: U.S. public inbred lines such as Mo 17, B-73, B-44, A-619, Oh 43, Oh 45, and H-51; older local inbred lines such as Punjab-7, and new inbred lines extracted from national breeding populations and commercial varieties.

The lack of a viable seed industry remains a major constraint in the delivery of improved genotypes to farmers. Only enough certified seed to plant 5% of the total national maize area is produced annually. Most of the certified seed is of open-pollinated varieties. Only about 13,000 ha are planted with hybrid maize in Pakistan. Most of this area is planted with hybrids developed by Rafhan Maize Products, Ltd., a corn starch company. Rafhan's hybrids are based on U.S. inbred lines (MO17, B73) as well as locally developed inbreds with resistance to leaf blights and stalk rots (personal communication, Khan Bajadur). Rafhan only distributes its hybrids to contract growers who produce grain for wet-milling.

Sri Lanka

Maize is the second most important cereal crop (after rice) in Sri Lanka. It is produced on about 50,000 ha and is used mainly for animal feed. Over 90% of the area is in the highlands and is irrigated. Maize breeding objectives include resistance to stem borer (*Chilo partellus*), stalk rots (Fusarium sp.), leaf blights (*H. turcicum*), and sheath spots. Populations are being formed using local materials and germplasm provided by CIMMYT (personal communication, R.N. Wedderburn). One of the most promising populations, Composite 6, is comprised of Thai composite, Cupurico x flint compuesto, and Poza Rica 7425. Various varieties from CIMMYT's populations 28, 29, 36, and 41 have also been introduced. Open-pollinated varieties and nonconventional hybrids (varietal and family crosses) are being developed. A yellow-grain variety developed from Suwan 1 was released in 1977 under the name of Bhadra 1.

Southeast Asia and Pacific

INDONESIA

Maize is the second most important cereal produced in Indonesia, after rice. During 1983-85, approximately 5.2 million t of grain were produced annually on 2.6 million ha, with national yields averaging 2.0 t/ha. Average maize yields have been increasing in Indonesia due to the rapid increase in the use of fertilizer, especially nitrogen, which is being sold at highly subsidized prices.

CIMMYT collaborates with the national maize program and regularly supplies international testing trials and makes staff visits to the country. More recently, IITA has supplied inbred lines with combined downy mildew and streak virus resistance to the national program and to a private seed company, P.T. Bright.

The maize seed industry is not well developed and only about 25% of the total maize area is planted with improved varieties. In the future, it is envisioned that both open-pollinated varieties and hybrids will have market niches. Two government agencies—Perem Sang Hyang Seri and P.T. Pertaini Patra Tani—produce some certified maize seed of open-pollinated varieties. In recent years, a number of private seed companies have also been established. Three transnational companies—P.T. Bright (division of Dekalb), Cargill, and Pioneer Hi-Bred—have released downy mildew resistant hybrids. Cargill's hybrid, C-1, is the most popular, and the seed demand for this genotype has outpaced supply (Timmer 1987). P.T. Bright is also selling an open-pollinated variety, Arjuna, which is derived from Suwan 2 developed at Kasertsart University in Thailand.

PHILIPPINES

Maize is the second most important cereal produced in the Philippines, after rice. During 1983-85, approximately 3.3 million t of grain were produced annually on 3.4 million ha, with national yields averaging 1.0 t/ha. Most improved cultivars (yellow and white) grown by farmers are open pollinated. Of the approximately 3.4 million ha annually planted with maize, only 1% of the total maize area is planted with hybrids and about 25% is planted with improved open-pollinated varieties.

Maize improvement research is conducted in the public and private sectors. The Institute of Plant Breeding (IPB) at the University of the Philippines, Los Baños, has participated in CIMMYT's international variety testing program since the mid-1970s (personal communication, M. Latin). IPB's maize breeding program has been primarily geared toward the development of superior open-pollinated varieties (composites). A modest hybrid breeding component of the program was initiated in 1980, and inbred lines have been extracted from several source populations. Some hybrids are being used in limited areas covered by the government's intensified maize production program.

Although CIMMYT has been a major source of germplasm, most of its material has lacked resistance to downy mildew, a major constraint to maize production in the country. IPB has also participated in a CIMMYT-coordinated project to improve several populations for downy mildew resistance, using Philippine and Thai source materials. They have tested experimental varieties with tropical adaptation. In 1986, IPB released its first variety based on CIMMYT germplasm, IPB Variety 4, a white flint based on Rampur 8075, derived from a downy mildew resistant population developed specially through the collaborative IPB-CIMMYT program. Since 1985, IITA has supplied inbred lines and populations to IPB and two private companies, the San Miguel Corp. and Pioneer Hi-Bred International (personal communication, S.K. Kim).

Currently four seed companies (one local and three foreign) produce hybrid maize seed in the Philippines. These companies produce hybrids that undergo an accreditation process based on agronomic performance trials coordinated by the Philippines Seed Board. Pioneer Hi-Bred has two downy mildew tolerant hybrids that are officially approved. Pioneer Hybrid 6181 is a yellow material released in 1980 and extensively grown in Southeast Asia. Pioneer Hybrid 3228 was released in 1985; it is better yielding than 6181 and has better tolerance to downy mildew. Parent lines in 6181 were derived from Thai Composite #1, Thai Comp. 3-4F4, and Cupurico x Flint Composite DMR. Cargill also has a downy mildew resistant hybrid released in 1983. The San Miguel Corporation has released two varietal hybrids with downy mildew resistance: SMC-101 (EV from Pop. 28 x Suwan 1) and SMC-102 (EV from Pop. 36 x Suwan 1).

Certified seed may be marketed either directly by the company or through local marketing companies and agricultural input suppliers. The open-pollinated varieties are produced and marketed by a limited number of small seed growers. These varieties do not benefit from a good seed production and distribution

Figure 13. Drs. Rachain Thiraporn, manager of Suwan Farm of Kasetsart University in Thailand, and Richard N. Wedderburn, a CIMMYT entomologist stationed in Thailand, view a test plot of corn. Much of the research on corn improvement in Thailand has been carried out at Suwan Farm. Source: CIMMYT.

system, and hence the rate of spread has been slow.

THAILAND

Maize is the second most important cereal grain produced in Thailand, and the country is a net maize exporter of more than 2 million t annually. During 1983-85, approximately 4.2 million t of grain were produced annually on 1.7 million ha, with national yields averaging 2.4 t/ha.

The Thailand National Maize Program has cooperated with CIMMYT since the mid-1960s and with various Rockefeller Foundation-supported collaborative maize research programs in Asia and in other continents. The CIMMYT international trials have been tested extensively in Thailand but have lacked suitable resistance to downy mildew. More recently, IITA has supplied its inbred lines and hybrids to public and private sector organizations in Thailand. Although CIMMYT and IITA materials have been used in forming new populations and in extracting inbred lines, no direct releases have been made from these materials.

The history of the development of Suwan 1 is the epitome of what international cooperation in germplasm development can achieve and has achieved. The story starts with the introduction in 1960 of the variety Tiquisate Golden Yellow (a mixture of two strains of maize of Cuban origin -a white semident and a golden yellow flint) from Guatemala. This variety was well adapted to Thailand and had a golden yellow semi-flint grain that was well regarded in international markets. Farmers took up this variety, and the maize area in Thailand began to increase rapidly.

Based on the adaptation of Tiquisate Golden Yellow in Thailand, the national program requested and

Table 9. Germplasm assembled in Thai Composite #1

Source	Group	Material
Caribbean Islands	Argentino	Cuba Gr.1
	Argentino	Cuba 11J
	Argentino	Puerto Rico Gr.1
	Tuson	Cuba 40
	Tuson-Carilla-Criollo-Tuson	Cuba 1J
	Tuson-Carilla-Criollo-Tuson	Cuba V59
	Tuson-Carilla-Criollo-Tuson	Antigua Gr.1
	Tuson-Carilla-Criollo-Tuson	Antigua Gr.2
	Tuson-Carilla-Criollo-Tuson	Puerto Rico Gr.2
	Tuson-Carilla-Criollo-Tuson	Barbados Gr.1
	Tuson-Carilla-Criollo-Tuson	Cupurico
	Tuson-Carilla-Criollo-Tuson	Caribb. Flint Comp.
	Tuson-Carilla-Criollo-Tuson	Comp. Caribb. Amarillo
	Tuson-Carilla-Criollo-Tuson	Tiquísate Golden Yellow x Caribb. Comp.
	Tuson-Carilla-Criollo-Tuson	Tiquísate Golden Yellow x Guadalupe 12D-14D
Mexico and Central America	Tuxpeño	Veracruz 163
	Tuxpeño	Veracruz 181
	Tuxpeño	Veracruz Gr.48
	Tuxpeño	Tamaulipas 8
	Salvadoreño	Salvadoreño Amarillo
	Argentino-Criollo	Tiquísate Golden Yellow
South America	Northern Catato	Guayana Francesca III
	Cuban Yellow Dent	Bahia III BCO
	Cuban Yellow Dent	Dentado Amarillo
	Argentino-Criollo-Tuson	Nariño 330-Peru 330
	Argentino-Criollo-Tuson	DV 103
India	Caribbean-Tuxpeño-India-U.S.A.	Composite A1
	Caribbean-Tuxpeño-India-U.S.A.	Multiple Cross 2
	Caribbean-Tuxpeño-India-U.S.A.	Multiple Cross 4
	Caribbean-Tuxpeño-India-U.S.A.	Synthetic A3B
	Caribbean-Tuxpeño-India-U.S.A.	Synthetic A11
Other	Tuxpeño-Caribbean-U.S.A.	Tuxpantigua
	Tuxpeño-Caribbean-U.S.A.	Veracruz 181 x Antigua Gr.2
	Tuxpeño-Caribbean-U.S.A.	USantigua
	Tuxpeño-Caribbean-U.S.A.	Florida Synthetic

Source: Sujin Jinahyon (1973)

received other tropical varieties and collections of Caribbean origin from the Mexican-Rockefeller Foundation program in Mexico. This germplasm development process was accelerated in 1966 with the shifting from India to Thailand of the Rockefeller Foundation-supported Inter-Asian Corn Program and the establishment of CIMMYT; both programs played an active role in the formulation of new national breeding materials.

In 1967, the Thai national program chose 36 germplasm complexes to form Thai Composite #1. General yield performance, adaptation in Thailand, and diversity of material by origin were the major criteria used in the selection of these germplasms (table 9).

A modified ear-to-row scheme was employed to systematically inter-mate all germplasm sources. In 1970, four cycles of selection were completed, and the composite was then officially named Thai Composite #1. By 1973, using S_1 progeny selection followed by recombination, three cycles of selection had been completed. In addition, 250 S_1 families were chosen during cycle 3 selection to form the sub-population Thai Composite #1 Early, which eventually became Suwan 2.

While Thai Composite #1 was 20% to 30% higher yielding than Tiquísate Golden Yellow, it faced a new problem by the time it was theoretically ready for release. Downy mildew, first reported in 1968, had spread rapidly across the maize growing areas of Thailand. Thai Composite #1, as were other Thai materials, was susceptible to downy mildew.

Stopgap measures were taken in 1973, and two varieties with some resistance to downy mildew, Bogor Synthetic 2 and Tainan 10, were imported for use by Thai farmers. Simultaneously, several sources of downy mildew resistance found in Philippine germplasm, DMR 1 and DMR 5, were backcrossed three times to the Thai Composite #1 in 1972 and 1973 (personal communication, B.L. Renfro).

The new material, called Thai Composite #1 DMR, combined high yield potential with the needed resistance to downy mildew; this was named Suwan 1 and released in Thailand in 1974. Since then, Suwan 1 has spread quickly to farmers' fields in Thailand, where it is still the major variety grown by farmers. It has also been released in some 20 countries of Asia, Latin America, and Africa (personal communication, B.L. Renfro).

Suwan 1 has also been used extensively by private plant breeding companies in hybrid development. This high-yielding, downy mildew resistant material has been crossed with elite inbred lines from the United States, Brazil, the Philippines, and elsewhere to produce excellent hybrids and varieties for tropical environments. Cargill released an open-pollinated variety in 1985, Cargill 357, based on Suwan 1 and South American germplasm. Pioneer Hi-Bred has released the Hybrid 3228, developed in the Philippines. Kasetsart University has also released a single-cross hybrid and a three-way cross hybrid based on the Suwan 1 germplasm complex.

Improved maize seed is produced by the Department of Agricultural Extension, Ministry of Agriculture and Cooperatives, and by several private seed companies. During 1984-85, it was expected that between 10,000 t and 13,000 t of certified maize seed of open-pollinated maize varieties would be produced. Hybrid seed production has been increasing very rapidly. In 1985, about 2,500 t was produced, compared to 30 t in 1981 (Pray 1987).

Vietnam

Maize is the second most important cereal produced in Vietnam. During 1983-85, approximately 500,000 t of grain were produced annually on 387,000 ha, with national yields averaging 1.3 t/ha.

CIMMYT supplies germplasm to the Vietnamese national maize program and two open-pollinated varieties based on these materials have been released: VM-1 (C_7 of Tuxpeño-1, Pop. 21) and MSB-49 (Pop. 49). Also, Suwan-2 has been released as TSB-2 and the Ganga 5 Composite as Ganga 5. In 1985, it was estimated that 80,000 ha in northern Vietnam were planted with VM-1 (personal communication, B.L. Renfro). A quality protein maize variety, Population 63, has been released (NRC 1988). MSB-31 (originally Suwan 8331) is under increase and has been approved for release.

East Asia

China

Maize is the third most important cereal grain in China, after rice and wheat, and China is the leading maize producer in the Third World. During 1983-85, approximately 68 million t of grain were produced annually on 18.4 million ha, with national yields averaging 3.7 t/ha.

Nearly two-thirds of China's maize area is temperate in environment with the remaining area subtropical-to-tropical in its growing environment. The main maize growing areas are the north central region with 8.4 million ha, the northeastern region with 5.6 million ha, and the southwestern region with 4.5 million ha. Most of the crop is planted on loess soils in northern China and under rainfed production conditions. The northeastern region has a climate similar to the U.S. Corn Belt.

Hybrids based on U.S. dent germplasm are used by 65% to 70% of farmers. The original double-cross hybrids introduced during the 1950s and 1960s were based on elite Chinese Flint germplasm crossed with U.S. Corn Belt lines, including 38-11, L289, W19, W20, W24, and M14 (Li Jingxiong 1987), By 1969 national maize breeders had stopped using older lines of both foreign and local origin. New inbreds have been developed with multiple disease resistance. Most hybrids in China are single crosses derived from these newer inbred lines. Of these genotypes, the widely adapted, the high-yielding hybrid Zhongdan 2, has been the most popular, covering up to 9.3 million ha at one time or other during the 1980s; this hybrid has good resistance to leaf blights and head smut.

Since 1974, Chinese maize researchers have also been breeding for improved protein quality in maize and expect high-lysine and high-oil maize will be utilized for livestock feeding and industrial purposes. A quality-protein maize variety, Tuxpeño 102, has been released (NRC 1988). Approximately 10 hybrids have been developed and have undergone regional testing. The best QPM hybrid available to date, Zhongdan 206, yielded within 4% of the normal protein hybrid, Zhongdan 2, and also showed good resistance to kernel rot (Li Jingxiong 1987).

CIMMYT has had increasing collaboration with Chinese maize research programs over the past 10 years. China has released two open-pollinated varieties based on CIMMYT's Tuxpeño materials: Mexican white-94 (Tuxpeño-1) and Mexican white-1 (Tuxpeño P.B. C_{15}). It is estimated that 100,000 ha—5% of China's more tropical maize-growing area—are planted with Mexican white-94 and Mexican white-1 (Li Jingxiong 1987). China has also used CIMMYT's Population 28 (Amarillo Dentado-2) to develop one of the inbred lines in Guangxi Top 4, a hybrid released in 1985. In addition, the male parent of Hybrid 203 is an inbred line (#079) extracted from CIMMYT quality protein maize Population 39. These materials are being grown in the southern part of the country where more tropical environments prevail. In 1986, the Chinese Academy of Agricultural Sciences also received 100 inbred lines from IITA as germplasm sources.

LATIN AMERICA

Mexico, Central America, and Caribbean

COSTA RICA

Maize is the second most important cereal produced in Costa Rica, after rice. During 1983-85, approximately 105,000 t of grain were produced annually on 62,000 ha, with national yields averaging 1.7 t/ha.

Maize research is conducted by the University of Costa Rica and the Ministry of Agriculture; both organizations cooperate with CIMMYT in germplasm development (Stewart 1985). Nationally released materials based on CIMMYT germplasm include TICO V-1 Mejorado (Tuxpeño P.B., C_{11}, Pop. 21), TICO V-2 (Mezlca Amarilla, Pop. 26), TICO V-5 (Pop. 26), and Diamantes 8043 (La Posta). In addition, a variety-cross hybrid based on Pop. 26 x Pop. 21 has been proposed for national release. In 1985, 90 t of certified seed were produced.

CUBA

Maize is the third most important food crop in Cuba, after rice and sweet potatoes. During 1983-85, approximately 97,000 t of grain were produced annually on 67,000 ha, with national yields averaging 1.3 t/ha.

Maize research in Cuba began more than 40 years ago and during the 1940s and 1950s produced some well-known and widely used genotypes such as Cuba Yellow and Pocy T-66. In the 1960s, little maize research was undertaken. During the 1980s, maize research and production has received a higher priority in Cuba's 5-year development plans. As such, CIMMYT collaboration is relatively new, beginning in 1982 (Sanchez and Scobie 1986). CIMMYT regularly supplies germplasm to the Cuban national maize program, which has released three open-pollinated varieties based on this material: Pichilingue 7928 (Pop. 28), Across 7926 (Pop. 26), and Across 7931 (Pop. 31).

EL SALVADOR

Maize is the major food staple in El Salvador. During 1983-85, approximately 497,000 t were produced annually on 242,000 ha, with national yields averaging 2.1 t/ha, the highest in the region. White-grain hybrids are the dominant maize materials grown in the country.

The Agricultural Technology Center (CENTA) is responsible for maize improvement research in El Salvador. It has had a long and close working relation-

Table 10. Tropical lowland maize varieties and hybrids released in Guatemala and containing CIMMYT germplasm, 1972-86

Variety name	Type	Grain color	Source material
ICTA B-1	OP	White	Tuxpeño-1 (Pop. 21)
ICTA B-3	OP	White	Tuxpeño-1 (Pop. 21)
ICTA B-5	OP	White	Blanco Cristal.-2 (Pop. 30)
La Maquina	OP	White	Mezcla Trop. Blanca (Pop. 22)
ICTA T-101	VC	White	Tuxpeño-1 x Eto Blanco (Pop. 32)
HB-10	FC	White	Male parent, Pop. 22
HB-11	FC	White	Female parent, Pop. 22
HB-19	FC	White	ICTA B-1 x Eto. Blanco
HB-33	FC	White	Family of Pop. 23
HB-67	FC	White	Family of Pop. 22
HB-69	FC	White	Family of Pop. 23
HB-83	DC	White	Family of Pop. 22 and inbred lines of Pop 29
ICTA A-4	OP	Yellow	Am. Cristal.-2, (Pop. 31)
ICTA A-6	OP	Yellow	Am. Dent. (Pop. 28)
HA-28	FC	Yellow	Family of Pop. 28
HA-44	VC	Yellow	Pool 21 x Ant. Ver. 181
Nutricta	OP O_2	White	QPM Tuxpeño

Source: National Maize Program, Institute of Agricultural Science and Technology, Guatemala.

OP = open-pollinated variety; VC = variety-cross hybrid; FC = family-cross hybrid; DC = double-cross hybrid; OPV O_2 = quality protein maize open-pollinated variety

ship with CIMMYT. Work to develop hybrids began in the 1960s. Today, three CENTA-developed hybrids, H-3, H-5, and H-8, are grown on 71% of the total national maize area. The female parent of these hybrids is derived from Tuxpeño material. The most recently developed hybrids are H-19, H-20, and H-33, which are now being tested by farmers. H-19 yields 30% more than H-3 and 10% more than H-5 and has ear rot resistance. New corn stunt resistant hybrids are in the experimental stage and appear very promising.

El Salvador is one of the few developing countries that is not only self-sufficient in maize seed but also exports seed to neighboring countries. In 1985, 3,000 t of certified seed were produced. This success is due to a well-focused national maize research program, a dynamic and progressive private seed industry, and a strict and efficient certification system.

Guatemala

Maize is the major food staple in Guatemala, and white grain is the preferred color. During 1983-85, approximately 1.1 million t were produced annually on 777,000 ha, with national yields averaging 1.4 t/ha. Maize is mostly grown by small land holders for direct food consumption. Guatemala is currently self-sufficient in maize and may soon become an exporter.

Corn research is conducted by the Institute of Agricultural Science and Technology (ICTA). ICTA was created in 1973 and organized outside the Ministry of Agriculture. One of its main objectives was to bring research into closer contact with both farmers and extension agents. Both USAID and the Rockefeller Foundation were involved. CIMMYT placed two scientists with ICTA for several years to help strengthen the maize research program. These scientists left a working base that ICTA's scientists have built on.

ICTA has developed a considerable number of high-yielding varieties and hybrids for lowland tropical areas based on CIMMYT materials (table 10). A quality protein maize variety, Nutricta, was also released in 1984. In 1985, 2,000 t of certified seed were

Figure 14. Entries in maize trials in Haiti. Source: A.I.D.

produced, with almost all of this used in the tropical lowland areas. It is estimated that 60% (120,000 ha) of the maize area in the western lowlands of Guatemala is planted with improved varieties and hybrids.

For the highlands, five improved open-pollinated varieties also have been developed using local materials: V-301 (white), Barcena 71 (yellow), V-302 and V-304 (yellows), and Chanin, which has a cycle of 160 days compared to 270 days for local materials (Stewart 1985). To date, no significant coverage has been achieved with these highland materials.

HAITI

Maize is the most important cereal produced in Haiti. During 1983-85, approximately 147,000 t of grain were produced annually on 157,000 ha, with national yields averaging 0.9 t/ha.

CIMMYT has had research staff in residence in the country since 1982, working with national maize program staff. CIMMYT supplies germplasm to the national program, and three open-pollinated varieties have been selected for national release—Carolina, based on Poza Rica 7427 (Pop. 27); La Maquina 7827 (Pop. 27); and La Maquina 7928 (Pop. 28). In 1985, 50 t of certified maize seed were produced.

HONDURAS

Maize is the most important cereal produced in Honduras. During 1983-85, approximately 520,000 t of grain were produced annually on 353,000 ha, with national yields averaging 1.5 t/ha. Currently, the country is a net exporter of maize.

The national maize improvement program has a long history of cooperation with CIMMYT, and previously with the Rockefeller Foundation. A number of open-pollinated varieties have been developed using germplasm supplied through this international cooperation (table 11).

MEXICO

Maize is the major food staple in Mexico. During 1983-85, approximately 13.8 million t of grain were

Table 11. Maize varieties released in Honduras and containing CIMMYT germplasm, 1958-85

Variety name	Type	Grain color	Source material
Sintetico Hondureño Tuxpeño	OP	White	Tuxpeño, several populations
Honduras B-104	OP	White	Tuxpeño-1 (Pop. 21)
Hondureño Planta Baja	OP	White	C_{17} of Tuxpeño P.B.
Guaymas B-101	OP	White	La Maquina 7422
Guaymas B-102	OP	White	Tlaltizapan (Pop. 43)
Guayape B-103	OP	White	Blanco Cristalino-2 (Pop. 30)
Guaymas A-501	OP	Yellow	Tocumen 7428
Guaymas A-502	OP	Yellow	Amarillo Cristalino-2 (Pop. 31)

Source: CIMMYT Maize Program

produced annually on 8.2 million ha, with national yields averaging 1.7 t/ha.

Although CIMMYT is headquartered in Mexico and shares historical ties with the national research system (Stakman et al. 1967), maize research collaboration between CIMMYT and national institutions has been quite weak until recently. Since the mid-1980s, CIMMYT has strengthened its collaborative ties with the maize improvement and crop management research programs of the National Forestry, Agriculture, and Livestock Research Institute (INIFAP). The national maize program tests CIMMYT's full range of germplasm undergoing improvement and conducts yield trials throughout Mexico. Out of these materials, a considerable number of improved open-pollinated varieties and variety-cross hybrids have been released by INIFAP for lowland, tropical conditions (table 12).

CIMMYT estimates that about 2.5 million ha are planted with these varieties; V-524 and VS-525 are the most widely grown.

In recent years, more emphasis has been placed on germplasm development for highland areas above 1,500 m. The CIMMYT-German Pool STR is providing useful germplasm to develop materials for the high elevations of the State Chihuahua. CIMMYT is supporting Mexico's highland germplasm development work through increased maize improvement activity for zones above 1,800 m.

Table 12. Maize varieties and hybrids released in Mexico and containing CIMMYT germplasm, 1970-85

Name	Type	Grain color	Source material
V-424	OP	White	Blanco Dentado-2 (Pop. 49)
V-425	OP	White	Pool 19
V-454	OP	White	Tuxpeño-Caribe (Pop. 29)
V-455	OP	White	Mezcla Trop. blanca (Pop. 22)
V-524	OP	White	Tuxpeño-1 P.B. (Pop. 21 C_{11})
VS-525	OP	White	La Posta (Pop. 43)
V-526	OP	White	Poza Rica 7843 (Pop. 43)
V-527	OP	White	Across 7926 (Pop. 26)
V-528	OP	White	Tropical Blanco Dentado
HV-313	VC	White	Blanco Dentado-2 x Lucio Blanco

Source: CIMMYT Maize Program.

Table 13. Open-pollinated varieties released in Nicaragua and containing CIMMYT germplasm, 1975-85

Name	Grain color	Source material
NB-100	White	Jutipa 7930 (Pop. 30)
NB-1	White	Tuxpeño-1 (Pop. 21)
NB-3	Yellow	La Maquina 7422 (Pop. 22)
NB-4	Yellow	Poza Rica 7822 (Pop. 22)
NB-5	White	La Maquina 7843 (Pop. 43)
NB-6	White	Santa Rosa 8043 (Pop. 43)

Source: CIMMYT Maize Program

In addition, the national maize program is collaborating with CIMMYT's recently initiated hybrid program. Approximately 6,000 lines have been provided for testing as potential parents for hybrid development. Various private seed companies are also active in Mexico: Pioneer Hi-Bred, Dekalb, Asgrow, Northrup King, and Cargill. These companies use CIMMYT germplasm extensively in their maize improvement programs. It is estimated that 800,000 ha are planted with hybrids sold by these companies (personal communication, Alejandro Ortega C.).

NICARAGUA

Maize is the major food staple in Nicaragua. During 1983-85, approximately 213,000 t of grain were produced annually on 172,000 ha, with national yields averaging 1.2 t/ha.

The national maize improvement program cooperates with the CIMMYT testing program. Five open-pollinated varieties have been released for commercial production after three to four testing cycles and some selection for reduced height and improved husk cover (table 13).

In 1985, 1,636 t of certified maize seed were produced; open-pollinated varieties make up 85% and hybrids 15% of this total (personal communication, H.H. Lizarroga). Two imported hybrids, DeKalb B-666 and Pioneer 5065-A, are also used.

PANAMA

Maize is the second most important cereal produced in Panama, after rice. In 1984, 80,000 t of grain were produced on 75,000 ha annually, with national yields averaging 1.1 t/ha.

Maize breeding is carried out by IDIAP, the national agricultural research institute, and the University of Panama. Close collaboration between CIMMYT and these institutions has existed for many years (personal communication, José C. Cedeño). Materials received from CIMMYT go through a recurrent selection program and testing for adaption in different parts of the country. Two open-pollinated varieties from this program have been released and are planted on a very small acreage. These are Tocumen 7428 and an intervarietal hybrid FAUP-1, both from CIMMYT-based material. Pioneer Hi-Bred International is the only company from which the government buys maize seed for resale to commercial users. Two Pioneer hybrids are used: X-304C and X-306B. During 1985, 93 t of certified maize seed were sold, mostly of these imported hybrids.

Andean Region, South America

BOLIVIA

Maize is the major cereal produced in Bolivia. During 1983-85, approximately 460,000 t were produced annually on 311,000 ha, with national yields averaging 1.5 t/ha.

CIMMYT cooperates with the national maize improvement program, and three open-pollinated varieties have been released that are based on CIMMYT material: CIAT V105, based on Poza Rica 7528; Tuxpeño O_2, based on Tuxpeño O_2 (Pop. 37); and Chuquisaca 7741, based on OPM Population 41.

COLOMBIA

Maize is the second most important cereal produced in Colombia (after rice). During 1983-85, approximately 870,000 t of grain were produced annually on 592,000 ha, with national yields averaging 1.5 t/ha.

The Rockefeller Foundation and Colombian Ministry of Agriculture started an agricultural program in the early 1950s and a strong maize breeding program was initiated (Stakman et al. 1967). Several outstanding germplasm complexes were assembled during the 1950s (see chapter 2), and a number of high-yielding varieties and hybrids were released for commercial production.

The maize program of the Instituto Colombiano Agropecuario (ICA) collaborates with the international germplasm development and testing network coordinated by CIMMYT. CIMMYT's Population 22 (Mezcla Tropical Blanca), Population 26 (Mezcla Amarilla), Population 27 (Amarillo Cristalino), Population 35 (Antigua x Republica Dominicana), Popula-

Table 14. Maize varieties and hybrids released in Colombia and containing CIMMYT germplasm

Variety	Type	Grain color	Germplasm sources
ICA V-109	OP	Yellow	Suwan 7726 (Pop. 26), La Maquina 7827 (Pop. 27), Tocumen (1) 7735 (Pop. 35), and Santa Cruz Porillo (1) 7835 (Pop. 35)
ICA V-155	OP	White	Tuxpeño 1 (Pop. 21)
ICA V-156	OP	White	Tuxpeño 1, C_{14} (Pop. 21)
ICA V-157	OP	White	Across 7522 (Pop. 22)
ICA V-258	OP	White	Tuxpeño Braquiticos
ICA H-353	VC	White	Tuxpeño P.B. (Pop. 21) x Diacol V351 (ETO)
Patia-1	OP	White	La Posta (Pop. 43)

Source: CIMMYT Maize Program

tion 43 (La Posta), and Population Tuxpeño-Braquiticos are important components in ICA's germplasm complexes MB 115, MB 220, MB 233, and MB 237 (personal communication, Gonzalo Granados).

Approximately 90% of the improved materials released in Colombia are hybrids and the balance are open-pollinated varieties. Six open-pollinated varieties and one varietal cross have been released in Colombia that contain CIMMYT germplasm (table 14).

ECUADOR

Maize is the second most important cereal produced in Ecuador, after rice. During 1983-85, approximately 257,000 t of grain were produced annually on 185,000 ha, with national yields averaging 1.4 t/ha.

CIMMYT has had a very close collaborative research relationship with the national maize program, especially for the development of improved floury maize for the highland areas of the Andes (Posada Torres 1986). CIMMYT's Andean Region Program staff stationed in Cali, Colombia, have focused their efforts in Ecuador on the development of lowland tropical early and full-season open-pollinated varieties and family hybrids (personal communication, Gonzalo Granados). A number of improved varieties and hybrids have been released for commercial production (table 15).

Table 15. Maize varieties and hybrids released in Ecuador and containing CIMMYT germplasm, 1978-85

Variety name	Type	Grain color	Source material
Highland materials			
INIAP-101	OP	White	Floury Pool 1, Compuesto Cacahuacintle
INIAP-130	OP	Yellow	Floury Highland Pop. 4
INIAP-131	OP	Yellow	Floury Pool 4
INIAP-180	OP	Yellow	Amarillo dentado duro
Lowland materials			
INIAP-526	OP	Yellow	San Andres 7528 (Pop. 28)
INIAP-527	OP	Yellow	Santa Rosa 7624 (Pop. 24)
INIAP-H550	FC	Yellow	Fam. San Andres 7528 x INIAP-515

Source: CIMMYT Maize Program

Table 16. Open-pollinated varieties released in Peru and containing CIMMYT germplasm, 1980-85

Name	Grain color	Source material
Lowland materials		
PMV-748	Yellow	Sete Lagoas 7728 (Pop. 28)
PMV-749	Yellow	Across 7728 (Pop. 28)
Jungle areas		
PMC 748	Yellow	Amarillo Dentado (Pop. 28)
PMC 749	Yellow	Amarillo Dentado (Pop. 28)
PMC 750	Yellow	Antigua Veracruz 181 (Pop. 24)
Marginal 28	Yellow	Amarillo Dentado (Pop. 28)
Highland materials		
Cajamarca 101	White	Floury Pool 1 (Comp. Cacahuacintle)
Cuzco 101	White	Floury Pool 1 (Comp. Cacahuacintle)
Santa Ana 101	White	Floury Pool 1 (Comp. Cacahuacintle)
Mal Paso 101	White	Floury Pool 1 (Comp. Cacahuacintle)

Source: CIMMYT Maize Program

Between 1977 and 1985, CIMMYT had a maize breeder stationed at the Santa Catalina Station, near Quito, who was engaged in developing improved floury and *morocho* types for national programs in the Andean region. This effort was very successful, and a number of improved highland materials have been released in Ecuador as well as other countries. INIAP 101 and INIAP 130 show the most commercial acceptance among farmers. The variety INIAP 526 is extensively grown by farmers in the lowland maize areas of Ecuador.

PERU

Maize is the most important cereal produced in Peru. During 1983-85, approximately 689,000 t of grain were produced on 304,000 ha, with national yields averaging 2.3 t/ha.

Ministry of Agriculture researchers began to carry out intervarietal evaluation trials in the 1940s at La Molina Experiment Station (Paz Silva 1986). This work led to the release in 1945 of several intervarietal hybrids: HLM-1, HLM-2, HLM-3, NS-50, and NS-54. These genotypes, known as "La Molina" hybrids, were grown in the coastal areas during the late 1940s and early 1950s. Maize researchers at the Canete Experiment Station produced "Top Cross de Canete" and "Sintetíco Harland" which were distributed in the early 1950s. These hybrids replaced Cuban Yellow, which had previously been the major improved genotype in use in coastal areas.

In 1950, the Rockefeller Foundation and the Government of Peru agreed to jointly collect Peruvian maize races and to preserve these materials in a properly equipped germplasm bank. In 1953, the Cooperative Maize Improvement Program (PCIM) was officially established at the National Agricultural University at La Molina, Lima. The Rockefeller Foundation, USAID, and the World Bank have contributed funds to PCIM, which has now been in operation for more than 30 years. In addition to the university maize improvement program, the Ministry of Agriculture initiated a separate maize breeding program in 1980 at INIPA, the National Agricultural Research Institute.

CIMMYT materials are being used extensively in both the PCIM and INIPA breeding programs for the coastal and jungle areas (Paz Silva 1986). In particular, CIMMYT Population 24 (Antigua x Veracruz 181), Population 26 (Mezcla Amarillo), Population 28 (Amarillo Dentado), and Population 36 (Cogollero) have been especially useful (personal communication, Gonzalo Granados). Various open-pollinated varieties have been released by PCIM and INIPA that

Table 17. Open-pollinated varieties released in Venezuela and containing CIMMYT germplasm, 1980-85

Variety name	Grain color	Source materials
FUNIAP-1	Yellow	Across 7328 (Pop. 28)
FUNIAP-2	White	Across 7740 (Pop. 40, QPM)
FUNIAP-3	White	Across 7523 (Pop. 23)
FUNIAP-4	White	Across 7843 (Pop. 43)
FUNIAP-5	White	Across 7822 (Pop. 22)

Source: CIMMYT Maize Program

utilize CIMMYT germplasm (table 16). The newly released variety Marginal 28 tropical is adapted to the jungle areas.

VENEZUELA

Maize is the most important cereal produced in Venezuela. During 1983-85, approximately 645,000 t of grain were produced annually on 368,000 ha, with national yields averaging 1.8 t/ha.

CIMMYT regularly supplies germplasm to the national maize breeding program. Experimental varieties from Populations 21, 22, 29, 32, and 43 have been used to develop a broad-based white grain germplasm complex (personal communication, Gonzalo Granados). Populations 21 and 32 also have been used as a source of inbred lines. Five open-pollinated varieties containing CIMMYT germplasm have been released for commercial use by the Fundación para la Investigación Agrícola y Promoción Tecnológica (FUNIAP) (table 17).

Southern Cone, South America

ARGENTINA

Maize is the second most important cereal in Argentina, after wheat. During 1983-85, approximately 10.4 million t of grain were produced annually on 3.1 million ha, with national yields averaging 3.3 t/ha; roughly 60% of national production is exported. Approximately 2.5 million ha are located in temperate environments and the remaining 0.6 million ha in subtropical environments.

Virtually all of the maize area in Argentina is planted with single-cross hybrids produced by private sector organizations. These hybrids involve inbreds developed from the Cateto Flints, Cuban Flints, and Coastal Tropical Flints on one side and U.S. dent inbred lines on the other (Wellhausen 1978). These hybrid combinations are the dark orange grain types preferred by the Argentinian grain board. CIMMYT's subtropical, late yellow flint and dent populations are used in Argentina as germplasm sources for the subtropical environments.

BRAZIL

Maize is the major cereal grown in Brazil. During 1983-85, approximately 20.6 million t of grain were produced annually on 11.6 million ha, with national yields averaging 1.8 t/ha, making Brazil the second largest maize producer in the developing world, after China.

During the 1950s and 1960s, Brazilian maize scientists made extensive use of exotic germplasm from the Caribbean Flint and Dent complexes to form new

Figure 15. Trials of floury maize in Ecuador highlands. Source: CIMMYT.

Table 18. Maize varieties and hybrids released by Brazil and containing CIMMYT germplasm, 1975-86

Name	Type	Color	Germplasm source
BR-5101	OP	White	Tuxpeño-1 (Pop. 21)
BR-5102	OP	Yellow	Amarillo Dentado (Pop. 28)
Centralmex Nordeste	OP	White	Tuxpeño-1 (Pop. 21)
BR-105	OP	Yellow	Suwan 1
BR-108	OP	White	Tuxpeño (C_7) (Pop. 21)
BR-126	OP	White	Tuxpeño-1 (Pop. 21)
BR-300	VC	Yellow	National cutivar x Suwan 1
BR-301	VC	White	Two CIMMYT Varieties (Closed Pedigree)
BR-302	TC	Yellow	Two CIMMYT Varieties (Closed Pedigree)
EMPASC 151	OP	Yellow	Amarillo Bajio (Pop 45.) x various temperate materials
EMPASC 152	OP	Yellow	Suwan 1
Piranao	OP	White	Tuxpeño Braquiticos

Source: CIMMYT Maize Program.

germplasm complexes that have substantially increased the yield potential of hybrids in Brazil (Wellhausen 1978). Seed of the related dent populations—Azteca, Maya, Piramex, Centralmex, IAC1—have all been widely distributed in the large region from northern Rio Grande do Sul to the Amazon basin. The Tuxpeño-based germplasm complexes have been especially productive in crosses with the Cateto Flints and Paulista Dents (derived from the interhybridization of Cateto and U.S. dents).

The Centro Nacional de Pesquisa de Milho e Sorgo (CNPMS) maize breeding program was started in 1975 through a technical cooperation agreement with CIMMYT. The program has actively tested a broad range of pools and populations from CIMMYT, and it is believed that in the next decade farmers in Brazil will be using, indirectly or directly, a great many commercial hybrids derived from CIMMYT germplasm.

Fifteen populations (CIMMYT) were chosen for additional research and different approaches for their utilization were used. From these populations, nine open-pollinated varieties and three varietal or top-cross hybrids have been released by the national maize program for use in different regions of Brazil (table 18). Selected CIMMYT populations are being used for inbred line development by private and government programs (personal communication, Ricardo Magnavaca). CNPMS may release several double-cross hybrids based on CIMMYT material. In 1987, EMBRAPA announced the release of a new hybrid, BR-201, which is tolerant of aluminum toxicity. Two populations of quality protein maize (QPM) have been selected from testing 23 populations of QPM material. Population 63-blanco Dentado-1 QPM and Population 64-Blanco Dentado-2 QPM may be released for a program of mixing white kernel flour with wheat flour.

Data from ABRASEM (Associacao Brasileira dos Produtores de Semutes, Brazilian Association of Seed Industry) indicate that 150,000 t of commercial maize seed was produced in 1984/85. CIMMYT derived populations may account for 1% of total seed production. Agroceres, a Brazilian seed company, markets 50% of all hybrid seed. International seed companies market 30% of hybrid seed, and the remaining 20% is marketed by small seed companies.

Chile

Maize is the third most important cereal in Chile, after wheat and barley. During 1983-85, approximately 668,000 t were produced annually on 129,000 ha, with national yields averaging 5.2 t/ha. (Average yields by 1986-87 had reached 7.0 t/ha.)

U.S. Corn Belt hybrids are well adapted to Chilean production conditions and are grown extensively throughout the country. (See chapter 4). Average national maize yields are consistently above 5 t/ha and rising. The adaption of U.S. hybrids in Chile has been good enough to justify the near-complete discontinuation of maize breeding research (Venezian 1987). The National Agricultural Research Institute (INIA) conducts some crop management research in maize and also has a small research project to develop an open-pollinated flint variety (Camelia) and for green ear corn. Some research on silage maize is also conducted in agricultural universities. CIMMYT materials are used to a limited extent in these modest national maize breeding projects.

Paraguay

Maize is the major cereal produced in Paraguay, and rapid growth in production has occurred during the past decade. During 1983-85, approximately 473,000 t of grain were produced annually on 390,000 ha, with national yields averaging 1.2 t/ha.

The national maize improvement program has collaborated closely with CIMMYT since 1981 and has evaluated many normal and quality protein maize pools and populations. Open-pollinated varieties currently in commercial production include Guaraní V-311, an improved version of Venezuela-1, and Guaraní V-312, based on Suwan 8027 provided by CIMMYT. The major hybrid in use is Pioneer 6875 from Brazil. A quality protein maize variety, Nutri-Guarani-V241, has been commercially released (NRC 1988).

4. SUMMARY OF USE OF IMPROVED GENOTYPES

Given the paucity of readily available data, estimating the area planted with improved maize materials and determining the origin of this germplasm are precarious exercises. The fact that high-yielding maize materials do not have a single common characteristic—such as the dwarfing gene—makes the tracking of area data on the use of improved germplasm more difficult. Moreover, since open-pollinated varieties are still the dominant genotypes in most developing countries and farmer-maintained and distributed seed is the major seed source, commercial records from seed sales are not available to gauge the actual use of improved open-pollinated varieties (OPVs). Finally, the complex genetic background of the new maize types developed, or being developed, also precludes a simple data compilation on the pedigrees of germplasm contained in these improved genotypes.

It is likely that the data reported by national programs on the area planted with hybrids are the most reliable, since there are more reasonable records of hybrid seed sold annually to farmers and thus more accurate estimates can be made of the area planted with these materials. The data on OPVs are much less reliable, especially since in the majority of the country cases, relatively little certified seed of OPVs is sold through an organized seed sector. While national maize research and production programs have attempted to introduce improved OPVs through extension demonstrations and seed-increase plots planted on farmers' fields, such informal seed delivery systems have not been able to maintain the genetic purity of the improved OPVs originally introduced, which invariably become contaminated by surrounding maize materials (often unimproved genotypes).

CIMMYT SURVEY OF IMPROVED MAIZE SEED USE

During 1985-86, CIMMYT conducted a survey to estimate the total maize area in the developing world planted with improved OPVs and hybrids. National program maize researchers and CIMMYT outreach staff were sent a questionnaire asking for figures on the amount of seed planted and the area of maize sown with improved genotypes. Maize seed enterprises were sent a different questionnaire soliciting data on costs, prices, yield, and other variables in the production of maize seed. More than 40 individuals and organizations responded to the questionnaires. This information became the basis of a report recently published by CIMMYT on the economics of commercial maize seed production in developing countries (CIMMYT 1987). Information was requested on three classes of improved genotypes: (1) hybrids, (2) commercial certified seed of OPVs, and (3) seed of improved OPVs maintained by farmers for their own purposes or traded among themselves. However, no attempt was made in the CIMMYT study to identify the pedigrees/parentages of the improved maize materials reported to be in use.

The CIMMYT maize study reports that improved genotypes are grown on about one-half (40 million ha) of the total maize area in the Third World. Thirty million ha of this area are planted with hybrids, which represents 38% of the total Third World maize area. Hybrids are grown primarily in temperate and subtropical production environments characterized by higher overall input use and commercial agricultural sectors. Three such countries—Argentina, Brazil, and China—account for 24 million ha, or 80% of the total Third World area planted with hybrids. Improved OPVs are reported to be grown on some 10 million ha, which represents 13% of the total maize area. This estimate includes the area planted with commercially purchased OPVs (7%) as well as the area planted with farmer-maintained seed of improved varieties (6%). Only a few countries reported a significant area planted with certified seed of improved OPVs, notably Thailand,

Tabie 19. Comparative use rates of hybrids and improved OPVs in important maize-producing developing countries[a]

	1983-85	1985-86		
	Maize area 000 ha	Percentage of area planted to:		
		Hybrids	Imp. OPVs	Total
Argentina	3,096	100	0	100
Brazil	11,583	63	7	70
Chile	129	68	13	81
China	18,403	72	0	72
Egypt	805	10	54	64
El Salvador	242	71	0	71
Guatemala	777	36	24	60
Kenya	1,547	61	5	66
Peru	304	7	43	[illegible]
Thailand	1,709	8	62	70
Zambia	512	53	11	64
Zimbabwe	1,450	60	17	77
Subtotal	40,557	66	7	73
Other developing countries	38,514	11	17	28

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

[a]Those producing over 100,000 t of maize annually.

Egypt, and Guatemala. In these countries, effective OPV research programs have been linked with viable seed industries resulting in substantial sales of improved open-pollinated varieties.

As would be expected, greater adoption of improved genotypes has occurred in those environments that are more favorable for maize production and among those farmers more oriented toward the commercial production of maize. In countries in which a considerable portion of the total area is planted with hybrids, patterns of adoption have usually followed a progression from local varieties to improved OPVs, next to nonconventional hybrids (varietal and family crosses), and then to conventional hybrids (single, double, and three-way crosses). The development of viable seed sectors, of course, has been a necessary condition for hybrid seed use.

At the country level, of the 54 countries that annually produce more than 100,000 t of maize, only 12 countries reported the use of improved genotypes on more than 50% of their total maize area (table 19). While small in number, these countries do account for about half of the total area planted with maize in the developing world. In the remaining 50% of the total Third World maize area, spanning some 40-plus countries, adoption of improved maize genotypes is less than 30%.

While the figures in table 19 should not be taken at face value, they do give some indication of the relative importance of improved open-pollinated varieties compared to hybrids. Similar caution should be used with many of the remaining tables in this section.

REGIONAL TOTALS

Regional maize production statistics and the proportion of total maize areas planted with improved genotypes in various developing regions are shown in

Table 20. Maize statistics for developing country regions

Region	1983-85[a] Area 000 ha	Yield t/ha	Prod. 000 t	1985-86[b] Percentage area planted with: Hybrids[c]	Imp. OPVs[d]	Total
Eastern and Southern Africa[e]	9,769	1.2	10,520	25	11	36
West and Central Africa	5,630	0.9	5,250	1	21	22
North Africa and Middle East	2,372	2.7	6,456	32	15	47
South Asia	7,493	1.3	10,005	11	23	34
Southeast Asia and Pacific	8,158	1.6	13,405	3	34	37
East Asia	18,905	3.7	70,766	71	1	72
Mexico, Central America, and Caribbean	10,204	1.6	16,567	26	16	42
Andean Countries, South America	1,761	1.7	2,923	20	9	29
Southern Cone, South America	15,295	2.1	32,854	70	6	76
Totals	79,071	1.7	136,156	38	13	51

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

[a]Based on 1985 FAO Production Yearbook.

[b]Data from survey conducted by CIMMYT in 1985-86.

[c]Includes conventional hybrids (single, double, and three-way crosses) and nonconventional hybrids (family crosses, variety crosses).

[d]Includes seed of improved OPVs retained by farmers.

[e]Does not include South Africa.

table 20. The highest rates of adoption are reported in the Southern Cone countries of South America and in East Asia, regions with relatively well-developed agricultural systems and temperate maize-producing environments. The lowest rates of adoption are reported in West and Central Africa and the Andean countries of South America, areas where maize is grown under low-fertility conditions primarily by resource-poor farmers for home consumption. Intermediate levels of adoption are reported in Mexico and in most countries of South and Southeast Asia. In these regions, adoption levels are lower than might be expected, especially when maize is compared to wheat and rice.

The following section reports country data on the use of improved OPVs and hybrids. Brief assessments of the major obstacles in increased use of improved genotypes are also offered. Summary statements are also made on the germplasm contributions that CIMMYT and IITA (and various predecessor maize research programs) have made and are making to national maize improvement programs.

Eastern and Southern Africa

This region exhibits great contrasts in the use of improved varieties and hybrids (see table 21). For the region as a whole, hybrids account for 25% of the total maize area and OPVs for about 11% of the total area. Functioning maize seed sectors have been established in South Africa, Zimbabwe, Kenya, and Zambia, as reflected by the high proportion of the total maize area planted with hybrids. Maize seed enterprises in most other countries in the region are undeveloped, and

Table 21. Comparative data for Eastern and Southern Africa on maize production and use of hybrids and improved varieties

Country	1983-85 Area 000 ha	1983-85 Yield t/ha	1983-85 Prod. 000 t	1985-86 Percentage maize area planted with: Hybrids	Imp. OPVs	Total
Angola	600	0.4	262	NA	NA	NA
Burundi	134	1.1	146	NA	NA	NA
Ethiopia	850	1.4	1,183	NA	NA	NA
Kenya	1,547	1.5	2,353	61	5	66
Madagascar	140	1.0	138	0	4	4
Malawi	1,162	1.2	1,397	9	17	26
Mozambique	600	0.6	338	NA	NA	NA
South Africa[a]	4,139	1.3	5,340	95	2	97
Somalia	138	0.9	130	0	6	6
Tanzania	1,483	1.1	1,593	5	7	12
Uganda	358	1.2	365	0	35	35
Zambia	512	1.7	863	53	11	64
Zimbabwe[a]	1,450	1.2	1,693	60	17	77

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

[a]Serious drought in these countries during 1983-84 severely depressed average yields and production (up to 50% below normal trend lines).

Table 22. Comparative data for West and Central Africa on maize production and use of hybrids and improved varieties

Country	1983-85 Area 000 ha	1983-85 Yield t/ha	1983-85 Prod. 000 t	1985-86 Percentage maize area planted with: Hybrids	Imp. OPVs	Total
Benin	485	0.7	370	NA	NA	NA
Burkina Faso	128	0.7	90	NA	NA	NA
Cameroon	443	1.2	510	0	30	30
Ghana	418	1.0	402	0	30	30
Ivory Coast	575	0.8	478	0	10	10
Nigeria	2,022	1.0	2,066	2	38	40
Senegal	84	1.2	101	0	30	30
Togo	179	1.1	191	3	30	33
Zaire	822	0.9	709	NA	NA	NA

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

Table 23. Comparative data for North Africa and the Middle East on maize production and use of hybrids and improved varieties

Country	1983-85 Area 000 ha	Yield t/ha	Prod. 000 t	1985-86 Percentage maize area planted with: Hybrids	Imp. OPVs	Total
Afghanistan	471	1.7	317	NA	NA	NA
Egypt	805	4.4	3,554	10	54	64
Morocco	405	0.7	267	NA	NA	NA
Turkey	560	2.9	1,627	33	13	46

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production.*

approximately two-thirds of the total maize area is planted with farmer-maintained OPV seed (local and improved varieties). In many countries, increased demand for improved genotypes will be closely linked to the increased use of fertilizer, since soil infertility is a major production constraint.

Good germplasm sources are available in most national programs for developing improved genotypes for the lowland tropics. CIMMYT's white grain populations have been used to develop varieties in Kenya, Tanzania, and Zambia. Streak-resistant populations and OPVs developed by IITA and CIMMYT have also been widely used in areas in which this disease is an important economic problem. IITA's tropical inbred lines and hybrids are also being used in several countries. More germplasm development work is needed to develop improved genotypes for the intermediate-elevation zones (1,000 to 1,500 m) of eastern and southern Africa, where some 3 million ha of maize is grown. To address these germplasm development challenges, CIMMYT and IITA launched a joint breeding program in 1985, in collaboration with the University of Zimbabwe, for the intermediate elevation areas.

West and Central Africa

The region has a very low percentage of maize area planted with improved genotypes (see table 22), and most countries have poorly developed maize seed enterprises. Only about 1% of the region's maize area is planted with hybrids. While it is reported that 20% of the total maize area is planted with improved OPVs, at least half of this area is planted with farmer-maintained seed. Thus, farmers rely on their own seed to plant approximately 90% of the total maize area. In general, soil infertility is a far more serious production constraint than inadequate germplasm. As such, the rate of adoption of improved genotypes will lag behind, and be a function of, increased fertilizer use.

IITA has made significant germplasm contributions to national programs through its streak-resistant materials. CIMMYT's lowland tropical white-grain populations and experimental varieties (many of which have been converted to streak-resistant types) have also been extensively used by national programs; improved OPVs based on CIMMYT and IITA maize materials have been released throughout the region. IITA's hybrid program has made significant contributions in Nigeria, where newly established hybrid seed companies are now producing increasing amounts of hybrid seed based on IITA's material.

North Africa and the Middle East

This region (see table 23) mainly has subtropical and some temperate environments. Maize production is significant only in Egypt and Turkey, even though nearly 5 million t of maize (primarily for use as poultry and livestock feed) is imported annually by countries in the region. Egypt and Turkey have reasonably well-developed and integrated maize research and seed systems in which private organizations are playing an increasingly important role.

CIMMYT's germplasm has been used extensively in varietal development in Egypt; IITA's inbred lines and hybrids have also been supplied to Egypt. CIMMYT's sub-tropical populations have been used in Turkey, although the primary genetic base used in national improvement programs is temperate germplasm from Europe and the United States.

Table 24. Comparative data for South Asia on maize production and use of hybrids and improved varieties

Country	1983-85			1985-86		
	Area 000 ha	Yield t/ha	Prod. 000 t	Percentage maize area planted with: Hybrids	Imp. OPVs	Total
Burma	185	1.7	317	0	34	34
India	5,896	1.3	7,759	13	23	36
Nepal	520	1.5	784	0	10	10
Pakistan	801	1.3	1,024	2	26	28

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

South Asia

Maize is an important crop in the region (see table 24). Except in India, virtually no hybrids are used, and most maize farmers in the region rely on their own seed of OPVs to plant nearly 80% of the total area. The relatively low percentages of the total maize area planted with improved genotypes is due primarily to internal inefficiencies within national maize seed sectors and the general lack of market development activities for maize and maize byproducts (poultry and livestock feed, sweeteners, oil). India and Pakistan have reasonably well-established seed production and distribution systems that function effectively for higher value crops such as wheat, rice, and cotton. However, inadequate price incentives in the maize seed sector and insufficient priority given to this crop in government development plans have resulted in relatively little commercial seed production of improved genotypes in these two countries. Maize seed producers are thought to be paid too little to do a quality job of seed production, and the profit margins allowed seed distributors are often so small that they are not interested in marketing maize seed.

CIMMYT's tropical and subtropical materials have been especially useful for increasing the disease resistance of national breeding populations that are primarily based on temperate-zone germplasm from the United States. CIMMYT's early-maturing populations are also being used extensively to develop shorter season varieties. In recent years, national programs in the region have also requested and been supplied with inbred lines and hybrids from IITA; these materials are still being evaluated but already are showing promise.

Southeast Asia and the Pacific

Adoption levels of improved genotypes vary considerably in this region (see table 25). Thailand has a well-established seed sector that markets primarily

Table 25. Comparative data for Southeast Asia and the Pacific on maize production and use of hybrids and improved varieties

Country	1983-85			1985-86		
	Area 000 ha	Yield t/ha	Prod. 000 t	Percentage maize area planted with: Hybrids	Imp. OPVs	Total
Indonesia	2,615	2.0	5,225	1	24	25
Philippines	3,361	1.0	3,331	1	25	26
Thailand	1,709	2.4	4,154	8	62	70
Vietnam	387	1.3	499	0	38	38

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

Table 26. Comparative data for East Asia on maize production and use of hybrids and improved varieties

Country	1983-85 Area 000 ha	Yield t/ha	Prod. 000 t	1985-86 Percentage maize area planted with: Hybrids	Imp. OPVs	Total
China	18,403	3.7	67,873	72	0	72
North Korea	423	6.1	2,593	NA	NA	NA

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

improved OPVs with downy mildew resistance, and most farmers use these improved genotypes. In Indonesia and the Philippines, farmers still rely on their own seed to plant between 80% and 95% of the total maize area. To date, little area is planted with hybrids though increased rates of adoption are anticipated, especially since considerable public and private sector research is now under way to develop hybrids. Private seed companies are increasingly active in Thailand, Indonesia, and the Philippines. Rapid rates of adoption of improved gentoypes—which increasingly will be hybrids—are expected throughout the region in the coming decade.

Scientists at Kasertsart University in Thailand, in collaboration with staff from the Rockefeller Foundation's Inter-Asian Corn Program, developed superior OPVs with downy mildew resistance during the 1970s. This germplasm complex (Suwan 1) has been extensively used by national programs within the region as well as in national programs elsewhere.

CIMMYT's tropical germplasm, though used by national programs in the region as parental material in hybrid development programs, has been susceptible to downy mildew. Beginning in 1980, CIMMYT began a concerted effort to introgress downy mildew resistance into three tropical lowland populations adapted to the region. As this is achieved, CIMMYT's germplasm will become increasingly useful to national maize improvement programs in the region.

IITA has also supplied tropical hybrids and inbred lines to various national program, including its white and yellow-grain populations with combined streak virus and downy mildew resistance. IITA's materials are showing promise and probably will be used in new hybrid combinations being developed in several countries of the region.

East Asia

This region is composed mostly of China and accounts for approximately 40% of total Third World maize production (see table 26). The major maize growing areas have temperate environments where maize attains high yield levels. China's temperate zones are planted with hybrids developed from Chinese, U.S., and European germplasm. In China's smaller subtropical maize growing area (in southern China, Hunan Province), CIMMYT's Tuxpeño-based populations (normal and quality protein maize) are being used extensively to develop new hybrids.

Mexico, Central America, and the Caribbean

Maize is the major crop in this region (see table 27). It is grown as a subsistence and a commercial crop, which partly explains the highly variable pattern in the use of improved maize materials evident within the region. The most effective seed sectors are found in El Salvador, Guatemala, and, to a lesser extent, in Mexico. In recent years, private sector seed companies have increased their activity in Mexico and Guatemala. Improved seed sector policies and more efficient seed production and distribution systems, with better linkages to maize research programs, can result in markedly higher levels of adoption of improved genotypes at the farm level in the near term.

Germplasm developed and distributed by CIMMYT and its predecessor organization has been used extensively in lowland tropical areas of Central America and the Caribbean. Virtually all improved OPVs and hybrids released by the national programs in this region are based on this germplasm. IITA has also supplied tropical hybrids and inbreds to several national programs in the region. Far less impact has

Table 27. Comparative data for Mexico, Central America, and the Caribbean on maize production and use of hybrids and improved varieties

Country	1983-85 Area 000 ha	1983-85 Yield t/ha	1983-85 Prod. 000 t	1985-86 Percentage maize area planted with: Hybrids	Imp. OPVs	Total
Costa Rica	62	1.7	105	6	14	20
Cuba	67	1.3	97	NA	NA	NA
El Salvador	242	2.1	497	71	0	71
Guatemala	777	1.4	1,062	36	24	60
Haiti	157	0.9	147	0	1	1
Honduras	353	1.5	520	NA	NA	NA
Mexico	8,234	1.7	13,765	25	17	42
Nicaragua	172	1.2	213	9	8	17

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

occurred in highland areas, where traditional varieties are still largely grown.

Andean Countries of South America

Maize is the major food crop in most countries of this region (see table 28). A large part of maize production is produced by resource-poor farmers for home consumption; these farmers tend to use their own seed. Hybrids are being grown on increasing areas in the lowlands of Colombia, Ecuador, Peru, and Venezuela, where maize is produced mainly as a commercial crop.

Germplasm from CIMMYT and its predecessor organizations has been extensively used by national programs in developing improved OPVs and hybrids for lowland tropical areas. Between 1977 and 1985, CIMMYT also participated in a collaborative research program with Ecuador's National Maize Program to develop improved OPVs of floury maize, the dominant genotype in many of the higher elevation maize environments of the Andes. Several superior OPVs have been produced through this program and have been released to highland maize farmers in several countries.

Table 28. Comparative data for the Andean countries of South America on maize production and use of hybrids and improved varieties

Country	1983-85 Area 000 ha	1983-85 Yield t/ha	1983-85 Prod. 000 t	1985-86 Percentage maize area planted with: Hybrids	Imp. OPVs	Total
Bolivia	311	1.5	460	NA	NA	NA
Colombia	592	1.5	870	13	2	15
Ecuador	185	1.4	257	3	29	32
Peru	304	2.3	689	7	43	50
Venezuela	368	1.8	645	30	13	43

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

Table 29. Comparative data for the southern cone countries of South America on maize production and use of hybrids and improved varieties

Country	1983-85 Area 000 ha	Yield t/ha	Prod. 000 t	1985-86 Percentage maize area planted with: Hybrids	Imp. OPVs	Total
Argentina	3,096	3.4	10,367	100	0	100
Brazil	11,583	1.8	20,638	63	7	70
Chile	129	5.2	668	68	13	81
Paraguay	390	1.2	473	NA	NA	NA
Uruguay	97	1.1	107	NA	NA	NA

Source: 1986 *CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.*

Southern Cone Countries of South America

This region (see table 29) has a well-developed maize economy with many high-yielding production environments, notably in Argentina and Chile. Effective maize research and seed production systems based on public-private sector cooperation have been established in most countries. Hybrid varieties are the dominant improved genotypes in use.

The hybrids grown i.. Argentina and Chile are based on U.S. and European germplasm. CIMMYT's germplasm contributions have been greatest to Brazil and Paraguay, countries with subtropical and tropical production environments. Several tropical x temperate gene pools assembled by CIMMYT have also proved to be valuable germplasm sources for national maize improvement programs in temperate areas in Argentina and Chile.

ACCELERATING THE USE OF IMPROVED MAIZE GENOTYPES IN THE THIRD WORLD

The diffusion of improved maize genotypes in developing countries has been adversely affected by many factors. These constraints can be classified under three headings: (1) those related to the physical and economic environment in which maize is produced, (2) those related to the focus and efficiency of the maize research system, and (3) those related to the effectiveness of maize seed sector.

The economic environment in which maize is produced in developing countries varies greatly and affects the diffusion of improved genotypes. Many Third World maize farmers operate on the fringe of the commercial agricultural sector and consume most of their harvest on the farm. Until these farmers participate more actively in the commercial agricultural sector, few purchased inputs will be used (including improved genotypes). In other resource-poor areas, such as in much of sub-Saharan Africa, low adoption levels of improved genotypes also are linked to other production constraints, especially soil infertility; until this more pressing yield constraint is relaxed, the diffusion of improved genotypes will be held in check.

National maize research systems must also ensure that they are producing technologies (improved varieties and management practices) that are appropriate to the needs and circumstances of target farmers. In some cases, the so-called "improved" genotypes released by national programs have not been sufficiently superior to the farmer's traditional varieties in yield potential and yield dependability to merit adoption. In other cases, the "improved" genotypes have not fit well within the farming system. For example, their maturity period is wrong, or they are not suitable for the cropping associations, or their storage and food use characteristics are not acceptable. Moreover, where maize production is carried out principally by resource-poor farmers, hybrids are often too costly a seed source even if they could be made available at the farm level. In such areas, the best opportunity for improving the genetic base of the maize materials continues to be improved OPVs in which farmers play major roles in seed multiplication and maintenance.

Finally, the maize seed sector must be able to produce and deliver quality seed of appropriate gene-types to farmers in an efficient and dependable way. In a number of countries, inadequate profit incentives (price policies) within national maize seed sectors have restricted the development of effective seed production and distribution systems. This is the case in South Asia, where reasonably well-developed seed sectors are operating for certain crops (wheat, rice, cotton) but do not function as well for maize. Here, the inefficiencies in the maize seed sector are holding back increased adoption of improved genotypes.

While the organization of maize research and seed sectors is a national matter, most successful systems—the major exception being China—have been built upon a public-private sector partnership. While each country must work out its own system, all successful maize research and seed partnerships have common elements (Douglas 1980). First, improved gentoypes developed by national programs must be appropriate to the needs and circumstances of Third World maize farmers. These varying circumstances indicate that both improved OPVs and hybrids have important roles to play in the maize economies of most developing countries. Second, once superior genotypes are developed, varietal evaluation and registration procedures must encourage their release and use, rather than retard this process through unnecessary bureaucratic obstacles. Finally, if effective maize seed production and distribution systems are to be developed, adequate incentives must be provided to seed producers, processors, and distributors. Cheap-seed policies have repeatedly shown that they retard the development of viable seed sectors and thus harm, rather than help, farmers.

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Appendix A

A NOTE ON SOME MAIZE BREEDING TERMS

Three breeding terms are used with some frequency in this report: hybrids, synthetics, and composites. Readers not familiar with these terms may find the following general definitions of assistance.

Hybrid—A single, double, or triple cross of selected inbred lines, normally with wide variability in genetic background, that attempts to enhance certain predetermined characteristics such as yield, insect or disease resistance, stalk strength, etc., and attain hybrid vigor or heterosis.

Synthetic—An open-pollinated variety derived from the combination of a number of selected self-pollinated lines, the good combining ability of which has usually been predetermined by testing several to all possible first generation (F_1) combinations.

Composite—An open-pollinated variety selected from the random combination of a large number of recognized breeding lines or accessions that in theory have good combining quality and the genetic characteristics desired for a specific location or purpose.

Synthetics and composites are generally developed for adverse or marginal maize growing conditions or where the technology, infrastructure, and demand for maize seed is not sufficient to make hybrid seed production viable.

(Adapted, with modifications, from Johnson et al. 1980.)

Appendix B

YIELD POTENTIAL OF TROPICAL HYBRIDS IN THE UNITED STATES

Holley, R.N., and M.M. Goodman. 1988. Yield Potential of Tropical Hybrid Maize Derivatives. *Crop Science* 28:213-218.

Abstract

In an effort to enhance the germplasm base of the U.S. maize (*Zea mays L.*) crop an adaptation program was initiated in 1975. A group of nine 100% tropical hybrids were crossed in all possible combinations, without reciprocals. Progeny from each cross were sib mated for six generations with selection for earliness, low plant and ear height, tassel and silk synchronization, lodging resistance, and prolificacy. Following sib mating, selection continued through two generations of selfing. All generations were grown in Raleigh, NC. In 1983 34 selected inbred lines were crossed onto two Corn Belt single cross testers, (A632Ht x B73) and (Mo17 x H95 x 99³). The number of entries representing each cross varied greatly depending upon response to selection. The testcrosses were divided into two groups by tester and combined with eight commercial check hybrids to form two tests. The tests were grown at three locations in 1984 and 1985, with three replications of each location. Testcrosses developed from 100% tropical inbred lines crossed with elite U.S. materials were agronomically competitive with commercial U.S. hybrids. The inbreds are adapted to the southern United States and flower about 1 week later than B73. Plant height and grain moisture of the testcrosses were all within the range of the commercial checks. About 25% of the testcrosses had yields comparable to the commercial checks. The inbreds are relatively insensitive to photoperiod as a result of the apparent presence of complementary genetic systems for photoperiod sensitivity among the different tropical materials.