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Improving on Excellence: Achievements in Breeding with the Maize Race Tuxpeño

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maize and wheat for the third world

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Introduction

One of the most graphic symbols of achievement in the CIMMYT Maize Program, oddly enough, is a downward drifting line, representing the dramatic reduction in plant height brought about in a population based on the Mexican landrace Tuxpeño. Why that particular accomplishment and that particular landrace should be assigned any special importance is a question we may well ask, considering that in the course of 20 years Center maize scientists have improved many diverse materials in exemplary, and sometimes astonishing, ways.

The answer to that question lies only partly in Tuxpeño itself. It is, without doubt, one of the outstanding germplasm complexes identified in Latin America, being widely adapted and inherently superior in many other valued characteristics. More important, however, are the ways in which various Tuxpeño materials have been manipulated and the benefits that have accrued from that work. The reduction of plant height is but one example (arguably the most important so far) in which a breeding project involving Tuxpeño has given rise, not only to germplasm that is useful in many parts of the world, but to new insights into the art of improving the tropical maize plant. In that case and many others, Tuxpeño has proved to be the right germplasm at the right time.

The question posed above, then, should perhaps be framed differently. Instead of wondering, "why give prominence to Tuxpeño?" we should ask, "how could one follow the story of maize improvement at CIMMYT without it?" Attempting to do so would be like reading a novel from which a principal character had vanished. One would be hard pressed either to follow the action or discern its meaning.

This booklet is not, however, intended to be a complete or systematic account of the Maize Program but rather touches fairly briefly on several important dimensions of its work over the years. Among the aspects considered are the nature of the germplasm with which CIMMYT scientists embarked on their improvement program and some of the assumptions and decisions they made about their work, goals and priorities they set, methods they applied, and results they achieved. Tuxpeño naturally enters into all of the issues discussed here, and in fact, one very convenient way of examining them is to focus on the attributes and various uses of that germplasm. It is hoped that this discussion will shed light on the progress of the Maize Program to its current position and offer some indications as to its future course.

A prehistoric funerary urn molded from dent maize ears (Courtesy of National Museum, Washington, D.C.)

A Gold Mine of Genetic Diversity

Tuxpeño is one of some 250 maize landraces found in the New World, most of which are represented in the CIMMYT Maize Germplasm Bank. These materials, referred to in an early annual report of the Center, as a "virtual gold mine for the further improvement of maize throughout the tropics," are probably the best repository we have for unique genetic variation. This resource has already yielded significant gains in maize breeding for developing countries and should increase in value as advances in biotechnology open up new possibilities for crop improvement.

A vital step toward conserving that resource and releasing its benefits was taken by scientists of the Rockefeller Foundation working in a cooperative project with Mexico's Ministry of Agriculture and Livestock. Over an approximately seven-year period during the 1940s, they collected and classified samples of maize from every region of the country and in the process developed the concept of maize landraces, which has subsequently come to be widely used in work on plant genetic resources.

This taxonomic category has a geographical and genetic component, corresponding to the two parts of its name, "land" and "race." Over many years of selection by farmers, each of the landraces acquired a distinct genetic identity and became suited to the growing conditions of a particular geographical area. That is why landraces are often closely adapted to the day length of certain regions and can readily be distinguished from one another by their grain and ear characteristics (a major criterion of early farmer-breeders in selecting for suitability to a preferred method of preparing maize). Across the whole geographical area where it was formed, a race will show substantial variation. Plants found at the extremes of the area, for example, differ from those originating nearer the center, though they still possess to a certain degree the characteristics by which the race is identified.

A collection of a particular race such as Tuxpeño contains numerous landrace accessions gathered over its entire geographic range. Those are among the materials with which breeders can work. Once selections have been made in the materials, however, they no longer constitute a landrace in the strict sense. Nevertheless, that germplasm will always show landrace ancestry, and one can refer to it as being of the racial stock of a material like Tuxpeño.

Multiracial ancestry and intense selection over many years account in large part for the high productivity of Tuxpeño.

The distinguishing features of Tuxpeño and the other Mexican races have been described by E.J. Wellhausen and others in *Races of Maize in Mexico: Their Origin, Characteristics, and Distribution*. The authors note that Tuxpeño has cylindrical ears with white dent grain and that it is quite tall (like most tropical maize), reaching a height of 3 to 4 m in its native habitat along the eastern coast of Mexico. They also suggest that Tuxpeño was formed by means of hybridization between two other races (Olotillo and Tepecintle), which in turn may have come about by means of hybridization between *harinoso* (floury) materials from South America and teosinte, a wild relative of maize. E.C. Gerrish has proposed in a *Crop Science* article that this "complex multiracial background" of Tuxpeño is an important reason for its productivity, along with the intense selection that has taken place in this material over the last 75 years. Some of its qualities, however, are perhaps better explained by conditions in the native environment of Tuxpeño. Having evolved on highly fertile soils under conditions fostering

high natural infection with ear rots and foliar diseases, it is inherently predisposed to respond to conditions of high fertility and possesses good resistance to those diseases.

Those are among the several reasons that, in the words of P. C. Mangelsdorf in *Corn: Its Origin, Evolution, and Improvement*, Tuxpeño is "the predominant modern race of the lowlands in eastern Mexico." Its name means "one from Tuxpan," a city located near the center of distribution of Tuxpeño in the state of Veracruz. Though most heavily concentrated there, however, this landrace is quite widely distributed, from the northeast of Mexico to the Yucatan, and its influence extends even beyond those bounds. It is the predecessor, according to Wellhausen and others, of some of the most productive and agronomically superior maize races of Mexico (such as Celaya, Chalqueño, and Conico Norteño) and is widely recognized as having had a strong influence on the dent maizes of the southern United States and ultimately on those of the North American Corn Belt.

More recently, through the work of Rockefeller Foundation scientists and their successors in the CIMMYT Maize Program, Tuxpeño has found its way to other continents and has proved useful to researchers and farmers in many lowland tropical regions of the Third World. Their experience appears to confirm that, as Mangelsdorf suggested, Tuxpeño is "one of the world's most productive corns."

Nigerian researcher in a trial plot of Tuxpeño varieties at the University of Ibadan.

Refining the Ore

The founders of the Maize Program recognized gold ore when they saw it, but they also knew that this raw material would have to undergo considerable refinement before yielding a substance that would be as highly prized in the tropics of Africa, for example, as it had been in Latin America. Those scientists set the refinement process in motion by examining the wide range of germplasm available and isolating from it Tuxpeño and four other germplasm complexes (the Cuban and Coastal Tropical Flints of the Caribbean, Salvadoreño of Central America, and Eto of Colombia) to form the basis of a maize improvement program.

From its Mexican roots, the program branched out rapidly in all directions and soon acquired a truly international character. By 1967 the five germplasm complexes, singly and in various combinations, were being put to diverse uses in many parts of the world. Tuxpeño proved to be a favorite in Central America, South America, Egypt, West Africa, and parts of Asia. Some of the most useful information that came out of this early work was that particular groupings of germplasm complexes showed much promise for the development of superior varieties. In Venezuela, for example, maize breeders found combinations of Tuxpeño and Eto to be extremely productive and began replacing a previous generation of improved germplasm with hybrids and open-pollinated varieties based upon those races. That same pairing later showed promise in other countries and is today an extremely important hybrid combination in the tropical world.

Tuxpeño not only demonstrated great potential for boosting productivity in crosses with other materials, but proved to be broadly adapted in the lowland tropics. Strong indications of this characteristic came from West Africa, where Tuxpeño and other materials were serving maize breeders as sources of resistance to tropical rust (*Puccinia polysora*). During the early 1950s, epidemics of this leaf disease had devastated local maize varieties along the coastal areas of the region. After Tuxpeño and other Latin American races were incorporated into West African breeding programs, however, no further epidemics occurred. By thus contributing to the stability of maize production, Tuxpeño was of direct benefit to farmers and consumers, but it also exerted an indirect and more far-reaching effect. The concrete demonstration that maize in West Africa could be improved through introduction of exotic germplasm gave impetus to variety development on the continent and provided eloquent testimony to the wisdom of putting maize research on an international footing, as was being done with rice and wheat.

In Quest of an Ideal Plant Type

Though CIMMYT maize breeders had high hopes for the tropical germplasm they were organizing, improving, and distributing around the world, they were well aware that this material had serious drawbacks and that its usefulness would be considerably lessened until something could be done about them. A major problem was that tropical maize is generally too tall and has relatively high ear placement. Two obvious consequences of these traits are difficulty in harvesting and a tendency for the plant to lodge under heavy tropical rains and high levels of nitrogen.

The Maize Program resolved to develop a more efficient tropical maize plant that would permit more efficient use of inputs.

Another problem was that, although it converts solar radiation into dry matter with roughly the same effectiveness as temperate maize, the tropical maize plant, in partitioning that dry matter, channels a lesser amount to grain and greater quantities to other plant parts; hence the lower grain yield potential of tropical maize. Bearing in mind the means by which maize production had been vastly increased in the US Corn Belt during recent decades, Program breeders foresaw what an impediment the inefficiency of tropical maize could be to improvement of the crop in many Third World countries. The rapid growth of US production was due in large part to the capacity of improved temperate genotypes to respond to improved management, consisting of higher plant densities, increased fertilizer application, and improved weed control. Neither component (improved germplasm

or better crop management) was completely satisfactory alone, but each was a necessary complement of the other.

This lesson was brought home during the 1950s to the many national and international organizations that had begun to promote the use of fertilizers for tropical maize. In one such project, conducted by the Food and Agriculture Organization (FAO) in Nicaragua, farmers adamantly refused to adopt the new technology. Their rejection derived, not from stubborn resistance to change, but, on the contrary, from a careful examination of fertilizer's effects on their maize crops. While improving grain production only marginally, fertilizer caused a "Green Revolution" in stem growth, which shot the tropical maize plants up to even greater heights than usual and exaggerated their already pronounced tendency to lodge. The missing element in this and similar projects was tropical varieties resembling the temperate type, a more efficient plant that would permit more efficient use of the inputs that were becoming more readily available to farmers in the Third World.

By 1968 Maize Program scientists had sketched the rough dimensions of the "ideal" tropical plant type and were resolved to make the germplasm conform to their picture. The plant they imagined would not, of course, be ideal in a strict sense, but would possess many characteristics that were considered important for most maize farmers in developing countries, such as a short, strong stalk, lodging resistance, the capacity to respond to applied nitrogen, a high ratio of grain to fodder, and resistance to major diseases and insect pests. At that early stage, however, the determination of CIMMYT scientists to effect those changes was not matched by a high degree of certainty as to the best method for doing so. They were still groping for the most suitable approaches to maize improvement in the tropics and, quite logically, gave this search even higher priority than the distribution of germplasm to other improvement programs.

A number of selection schemes were applied to Tuxpeño germplasm, among them mass selection in Tuxpeño Crema I, a population formed in 1965 by plant breeder Elmer Johnson from a collection of the best available germplasm of the race. The trouble with this and other schemes, however, was that selection was practiced for grain yield without taking into account the competitive advantages of tall plants. As a result, plants became taller and later maturing, thus complicating the task of intensifying the management of this tropical maize by means of increased fertilizer rates and higher plant densities. Mainly for that reason, mass selection in the Tuxpeño population was terminated in 1970.

Opting for recurrent selection was a little like taking the stairs down rather than the elevator, but the time and effort expended were more than justified by the results achieved.

As they proceeded with testing of methods for general utility in maize improvement, Program scientists began investigating three alternatives for the specific purpose of reducing plant height. These were (1) crosses between Tuxpeño Crema I and various sources of the dwarf mutant gene Brachytic-2, (2) crosses of that population to other germplasm, such as the population Antigua, that was already characterized by short plants, and (3) direct selection for reduced plant height in Tuxpeño Crema I. That population was a natural candidate for the work in view of its relatively good responsiveness to high fertility and its inherent tendency not to root lodge. It already had an edge on many other maize materials in two key features of the plant type the Program was seeking to develop.

On the face of it, introduction of the dwarfing gene must have seemed like the more promising of the three approaches, particularly since a quick reduction in plant height had already been achieved in wheat by means of a similar approach, using the Norin-10 dwarfing gene. What had been a brilliant idea in wheat, however, failed to shine in maize. As is too often the case in plant breeding, improvement in one characteristic proved detrimental to others. Plants into which the Brachytic-2 gene was introduced had greatly shortened lower internodes and were therefore more resistant to lodging. But they also tended to give low yields, were late maturing, showed increased barrenness, and had an odd appearance that was less than pleasing to the breeder's trained eye. Even had they lacked those disadvantages, plants shortened by means of the Brachytic-2 gene would rapidly have lost this trait through outcrossing to tall local materials.

Although work with the dwarfing gene continued for several years, recurrent selection over numerous cycles to achieve gradual reduction in plant height turned out to be a more satisfactory approach and more efficient than crossing with short populations such as Antigua. Opting for the recurrent selection scheme was a little like having to take the stairs down instead of the elevator, but the time and effort expended were more than justified by the results achieved.

That program, which continued for 21 cycles (ending only in 1979), was an offshoot of mass selection in Tuxpeño Cremo I. During 1967, superior families were culled from the third cycle of mass selection to initiate the project for reducing plant height. CIMMYT scientists rightly surmised that more rapid progress could be made in improving the population by selecting mainly for that trait, which was a chief feature of the ideal plant type and which they suspected would prove to have a direct relation with several other desirable characteristics.

The Downward Drifting Line

In retrospect, their suppositions seem eminently reasonable, but at that time the eventual outcome was far from guaranteed. Several pointed questions arose that could not be answered with certainty for lack of empirical evidence. To what degree, for example, could breeders alter the height of the maize plant drastically without hindering progress in the improvement of other traits? How could they influence the distribution of nutrients taken in by the plant among various plant parts? Would not short plants be inherently early maturing and therefore lower in yield potential? And would not numerous cycles of selection for short plants eventually exhaust the genetic variability of the population for this trait?

Any doubts about the wisdom of selecting repeatedly for short plants were laid to rest by a two-year multilocational evaluation begun in 1978 with cycles 0, 6, 9, 12, and 15. In that study, Maize Program staff observed a 37% linear reduction in plant height (from 282 to 179 cm) over the 15 cycles. Far from diminishing other desirable traits, this reduction improved the ability of the population to respond to higher plant densities without lodging (the density resulting in maximum grain yield increased from 48,000 to 64,000 plants per hectare), while reducing barrenness.

Elmer Johnson in a demonstration plot of cycles of selection for short plants in Tuxpeño Crema I.

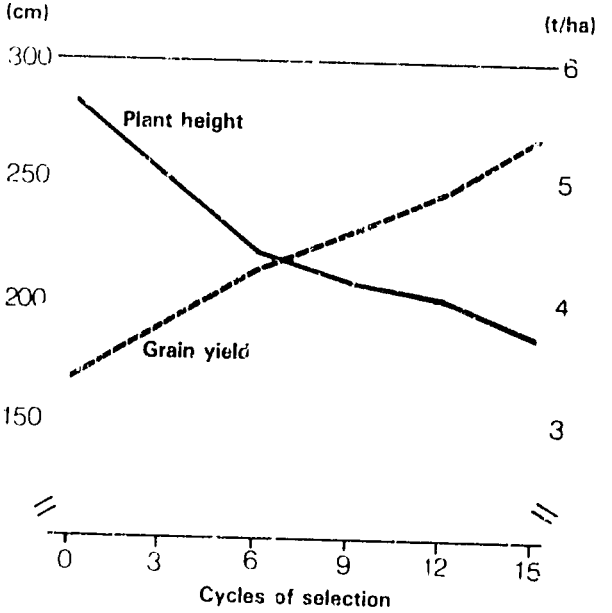
Largely as a result of those improvements, yield potential at the optimum plant density for grain yield was increased at a rate of 4.4% per cycle, while time to maturity decreased by less than 0.5% per cycle. Yield increases were observed at all three test sites, even though one of them (near Ciudad Obregon, Mexico) is extremely hot and not very productive for maize, suggesting that reduced plant height brought about some improvement in stress tolerance. Moreover, in another study of short plants selected from Tuxpeño Crema I (conducted on farmers' fields in Veracruz), it was demonstrated that they yield acceptably even under conditions of low nitrogen supply and poor weed control. Those results indicated that the population is well endowed with yield stability and should therefore be of particular value to small-scale farmers in the tropics, where maize-growing conditions are often marginal. To realize the higher yield potential of this material, however, farmers have to plant at higher densities than are usually customary in the traditional maize farming of the tropics.

In altering the appearance and performance of Tuxpeño, scientists had essentially recast this pre-Colombian tropical race in the mold of a modern, improved variety.

The increase in yield potential was accompanied by welcome adjustments in the functioning of the maize plant. The most significant one was that, as the population became shorter, plants began to allocate a smaller proportion of total dry matter to the stem and sheath and a larger amount to floret and kernel development. This shift in resources was sufficient to boost the harvest index from 0.30 to 0.45 (compared to 0.50 to 0.55 for temperate germplasm) between the original and fifteenth cycles. In thus altering both the

appearance and performance of Tuxpeño, CIMMYT scientists had essentially recast this pre-Columbian tropical landrace in the mold of a modern, improved variety.

One of the most persistent doubts raised about selection for short plants was that it would eventually drain the population of its genetic variability for this trait. Subsequent studies do suggest that there is a limit to the amount of yield improvement that can be gained through selection for short plants. But the linear decrease in plant height over 15 cycles (a trend which, according to further studies, continued even to cycle 18) clearly indicates that there is still sufficient genetic variation for plant height in the population.



Effect of plant height reduction on grain yield (at optimum plant density for yield performance) of Tuxpeño Crema I, grown at six location/years in Mexico, 1978-1980.

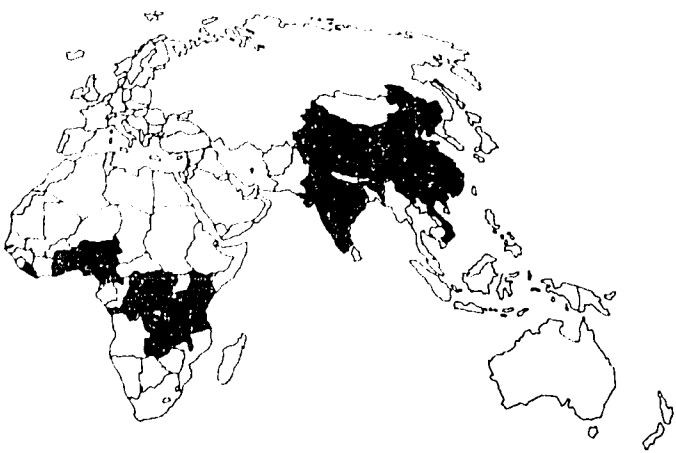
The Tuxpeño Legacy

Long before the later cycles of selection for short plants, maize researchers had already begun to make use of the Tuxpeño germplasm employed in the project. Out of cycle 7, for example (completed during the second season of 1970), a progeny trial was formed to test the progress of selection and was sent to several countries, including Zaire, where CIMMYT was involved in a bilateral project. Researchers there selected the 10 best families from the trial and formed the variety Salongo. In much the same way, many varieties were formed from cycle 11 in several Central American countries, including Hondureño Planta Baja, ICTA B-1 (Guatemala), Tico V-1 (Costa Rica), and Tuxpeñito V524 (Mexico).

Later cycles of selection were employed by some maize breeding programs to reduce the plant height of superior local germplasm. Researchers in Costa Rica accomplished this purpose by crossing cycle 17 with their own materials (in what proved to be an efficient alternative to many years of recurrent selection for short plants), and scientists in Panama carried out a similar procedure to develop a variety for the Chiriqui region.

Countries in which varieties or hybrids containing Tuxpeño germplasm have been released.

Partly because of its manifold effects on the subsequent thinking and practice of the Maize Program, the reduction of plant height in Tuxpeño continues to benefit maize scientists in developing countries. Products of this work are well represented, for example, in CIMMYT's current maize population improvement scheme, which took shape in 1973 and since then has resulted in the development of more than 850 experimental varieties. These and other materials from the Program have contributed to the development of more than 150 varieties or hybrids (about 45% of which contain a substantial proportion of Tuxpeño germplasm) by scientists in 43 countries. In almost all of the populations being handled by the maize improvement program, plant height has been reduced according to the same procedure applied to Tuxpeño Crema I. The eleventh cycle of selection in that population is now designated Population 21 (Tuxpeño-1), and cycle 17 has become Population 49 (Blanco Dentado-2). Many other populations consist entirely or partly of Tuxpeño germplasm derived from Tuxpeño Crema I or other sources. This germplasm has also proved useful in the Maize Program's work on



quality protein maize and is the basis for QPM varieties that have been released in Guatemala and Paraguay.

Another legacy of early work on Tuxpeño has been a series of special breeding projects (with varying relations to the mainstream of maize improvement at CIMMYT), which have employed Tuxpeño germplasm and in some sense derived inspiration from the program of plant height reduction. Though none of the more recent efforts have had quite the impact of that project, each represents an important step forward in germplasm improvement.

Partly because of its manifold effects on the thinking and practice of the Maize Program, reduction in plant height continues to benefit maize scientists in developing countries.

Reduced tassel and leaf size - The work on plant height was not the Maize Program's only attempt at getting tropical maize plants to channel more of their nutrients to the ear rather than other plant parts and thus to become more efficient users of resources. In 1975 a project was initiated in which recurrent selection for reduced tassel and leaf size was carried out over six cycles in three populations (including Tuxpeño-1) to accomplish that same end.

The success of selection for short plants confirmed the general principle that diminishing the flow of nutrients to one place by altering a plant part (such as the stem) would force them to go somewhere else and that a plant could thus be made to assign higher priority to grain production. Program scientists reasoned that this principle might be applied to additional plant parts and decided to test the assumption with tassel and

leaf size, two other characteristics in which tropical maize is excessive by comparison with temperate germplasm.

In concentrating on tassel size, scientists were supposing that a kind of war of the sexes was going on between the male and female flowers in maize over control of nutrients. It followed that, by curtailing the flow of nutrients to the tassel (through selection for fewer tassel branches, resulting in reduction of its apical dominance), more of these resources could be made available to the ear. It was also thought that large leaves in the upper parts of the plant shaded leaves near the ear, thus leading to reduced ear growth.

That line of thinking proved to be essentially correct, and selection for reduced tassel size, leaf size, or both brought about much the same sorts of improvement as had selection for reduced plant height, though at a slower rate of gain per cycle. As the number of tassel branches and leaf size were lessened through selection, optimum plant density for yield as well as maximum grain yield were increased. Improvement in yield was largely the result of a greater proportion of total dry matter being partitioned to the ear.

Drought tolerance—Recurrent selection for drought tolerance was another product of the successful marriage in CIMMYT's Maize Program between plant breeding and physiology. This project, however, involved a somewhat broader and more complex application than had been tried before of lessons learned in the work on plant height.

Selection for changes in some typical features of the tropical maize plant had, among other things, led to improvement in stress tolerance. "Why not," asked Program scientists, "quicken the pace of improvement in that trait (a critical one to maize growers in many developing countries) by concentrating on it more exclusively, much as was being done to reduce plant height?"

The first order of business was to choose a population for improvement of tolerance to drought. Cycle 12 of selection for short plants in Tuxpeño Crema I (under the name Tuxpeño Drought) seemed to be the most promising candidate for this task because it had given high and stable yields across many rainfed sites in the Maize Program's first set of Experimental Variety Trials (EVTs) conducted in 1973. As in the other projects discussed above, scientists' aim was to alter complicated and unseen physiological conditions in the maize plant, in this case its ability to endure moisture deficits.

Field assistant Pedro Gálvez Marín determining extension of leaf and stem under drought stress, one of five selection criteria applied in work on Tuxpeño Drought.

Since it was not feasible to select for this trait directly on a large scale, indirect selection criteria had to be found. Of the numerous possibilities, scientists settled upon five indicators: 1) rates of tissue elongation, 2) synchronization of male and female flowering, 3) rate of leaf death, 4) yield, and 5) temperature of the crop canopy. All of these can be gauged fairly rapidly, and measurement of only one, canopy temperature, requires the use of special equipment. The selection index based upon the five criteria was certainly a more elaborate affair than selection for reduced plant height or tassel size. But all five were considered to be useful, since drought tolerance is a trait with various physiological manifestations, each of which can be altered by means of a selection criterion.

Several evaluations of this project have been carried out. After three cycles of improvement, a test of Tuxpeño Drought under three levels of stress showed that, under severe drought stress, selection had improved synchronization of flowering, decreased barrenness, and brought about an average yield increase of 9.5% per cycle. In a second evaluation after six cycles of selection, however, the rate of improvement under severe drought stress had fallen off somewhat, suggesting a drop in the population's variation for the traits being selected. A study is currently being conducted to examine that possibility.

In the meantime, CIMMYT's research on drought resistance is entering a new and expanded phase. Methodologies developed in the course of the project with Tuxpeño Drought are being applied on a larger scale with additional materials, one of which is La Posta (Population 43), another Tuxpeño material. A second new avenue of research involves the formation of a special subtropical drought resistant pool, a composite of various sources of drought tolerance that will be crossed to cycle 8 of selection in Tuxpeño Drought.

Resistance to maize streak virus--With the reduction of plant height in Tuxpeño and other germplasm, tropical maize acquired the form and other essential features of a more nearly ideal plant type. The aim of much subsequent breeding work by CIMMYT maize scientists has been to add important finishing touches to the germplasm that will increase its efficiency in the use of resources and multiply its utility to maize scientists and farmers around the world.

Finishing touches are being added to improved Tuxpeño germplasm that will increase its efficiency in the use of resources and multiply its utility to maize scientists and farmers around the world.

Development of drought tolerance is one example of that type of work; breeding for disease resistance is another. Both are critical to the improvement of yield stability, a quality given high priority by most farmers in developing countries. The need is especially great in Africa, where drought, insect pests, and diseases cause violent fluctuations in crop yields, leading to severe food shortages in some years and retarding progress toward a more vigorous agriculture over the long term. Genetic resistance is the cheapest and most practical means of stabilizing African maize production, in view of the limited use of fertilizers, pesticides, irrigation, and other means of protecting and improving the maize crop. It is also a prerequisite for wider and more efficient use of those inputs. As they become more readily available in Africa, there will be little incentive for farmers to purchase them unless maize varieties are available that possess some inherent protection against conditions that in a matter of weeks could wipe out a crop of nonresistant maize and cancel any investment that had been made in fertilizer and other inputs.

Although much work remains to be done, particularly on drought, excellent progress has been made in the development of varieties with resistance to the maize streak virus (one of the more economically damaging diseases in sub-Saharan Africa), and these are now being deployed by maize improvement programs across the continent. To reach that stage, several paths were taken by scientists from CIMMYT and the International Institute of Tropical Agriculture (IITA) in a cooperative disease-resistance program begun during 1980. One approach was recurrent selection in the Tuxpeño population La Posta, chosen because it was already much in demand among African maize programs. Since maize streak virus is found only in Africa, it was decided that resistance could be developed most efficiently in La Posta by shifting improvement work from CIMMYT stations in Mexico to IITA headquarters in Nigeria. There the population has

Comparison of streak-resistant (SR) varieties with their nonresistant counterparts under artificial streak infection in Nigeria, 1983

Variety	Grain yield (t/ha)	Streak rating (1-5)*
Poza Rica 7822	0.9	5.0
P.R. 7822-SR BC_2	7.0	2.3
Across 7729	1.1	5.0
Across 7729-SR BC_2	7.1	2.3
Poza Rica 7843	1.5	5.0
Poza Rica 7843-SR BC_2	7.4	2.5
Across 7728	0.9	4.8
Across 7728-SR BC_2	6.7	2.3
Tocumen (1) 7835	1.4	3.5
Tocumen (1) 7835-SR BC_2	5.1	1.3

* 1 = resistant and 5 = susceptible.

been subjected to artificial infestation with the leafhopper vector of the streak virus and selection practiced for resistance.

This approach proved to be extremely effective in capitalizing on the genetic variability for streak resistance that was detected in La Posta at the outset of the program. Whereas in 1980 only 4.6% of the selected families had plants showing resistance, in 1984, after three cycles of selection, every family screened at IITA had some plants with streak resistance. Now, after further selection, the level of streak resistance within families is even higher, and varieties are being derived from the population for distribution to African maize scientists.

Other means of developing streak resistance rely heavily on Tuxpeño as well. One of those is to add resistance through backcrossing to experimental varieties formed from various CIMMYT and IITA populations. Of the dozen populations involved, nearly half consist partly or entirely of Tuxpeño germplasm. A number of the "converted" varieties have been tested widely in Africa, and some are already being multiplied and released to farmers in Benin, Nigeria, and Togo.

Conclusion

The task of putting finishing touches on improved maize populations will, of course, be a never-ending one. Many important modifications in this germplasm are still far from complete, and numerous other challenges will arise as maize production in the Third World evolves and as maize scientists come to understand more perfectly the germplasm requirements of the world's numerous and extremely diverse maize-growing environments.

Meeting those challenges will require, as it has in the past, various forms of cooperation between CIMMYT staff and their colleagues in national maize programs. In developing new germplasm for those scientists and in sharing ideas and techniques with them for employing this material, the overall pattern of the Maize Program's work will remain essentially the same, though some details may change.

Researchers must keep in view the difficult realities of maize production today in developing countries, while sharing farmers' hopes and making provisions for changes tomorrow.

One enduring element is the notion of an ideal plant, which has guided all of the work with Tuxpeño as well as with other materials. Staff of the Maize Program will persist in their efforts to develop germplasm that responds to fertilizer and other improvements in crop management but that, by virtue of its tolerance to physical stresses and resistance to diseases and insect pests, offers a distinct advantage to the great majority of farmers in developing countries who do not have access to other means of protecting the maize crop and improving its productivity. The attitude implied by this goal will also remain unchanged, namely that

maize scientists must keep in view the difficult realities of maize production today in developing countries, while sharing farmers' hopes and making provisions for beneficial changes tomorrow.

A second element that can be traced through the whole course of work with Tuxpeño and that will continue to characterize maize research at CIMMYT is a belief that even seemingly remote breeding objectives can be accomplished if the following three components are present: (1) superior germplasm, (2) efficient breeding methodologies, and (3) imaginative, innovative scientists.

Through the efforts of many researchers over the years, the first component has been made a permanent feature of the Maize Program, which is now well stocked with superior germplasm. Of the many materials available, Tuxpeño, because of its

Training officer Willy Villena with participants in a course on maize improvement.

proven utility, will continue to be a principal character in the story of maize improvement for developing countries.

We can also be fairly certain of the second component, since in the space of just two decades, researchers at CIMMYT and in other institutions have accumulated a wealth of experience with various techniques for improving maize. Consider, for example, that in all of the special projects discussed in this publication a different methodology was adopted. It is primarily in this matter of breeding approaches that one can expect to see some variations in the details of the Maize Program, as additions and adjustments are made to increase the efficiency of its germplasm improvement efforts. Recent examples are the development of special-purpose gene pools for work on insect resistance and the creation of a hybrid program, both of which will not only supply new germplasm products, but add to the store of knowledge and techniques available to maize researchers.

About the third component, one cannot easily make predictions. Suffice it to say that Tuxpeño did not turn out to be the right germplasm at the right time entirely by chance and CIMMYT scientists did not come upon appropriate methods for improving this material strictly through trial and error. The correct combination of superior germplasm and an efficient breeding methodology for the task at hand was conceived in the imaginations of skilled maize researchers, and continued improvement in maize will be as much a product of their creative ability as of the materials and methods themselves.

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