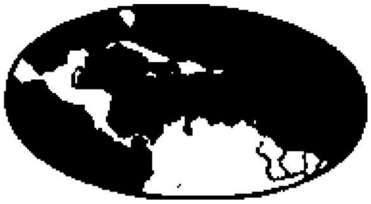
Joint symposium on maize and peanut. Held in Suriname
on behalf of the 75th Anniversary of
The Agricultural Experiment Station of Paramaribo.

November 13 – 18, 1978



Proceedings of the Caribbean Food Crops
Society. Vol. XV, 1978

POPULATION IMPROVEMENT AND VARIETAL DEVELOPMENT IN CIMMYT'S MAIZE PROGRAM

S.K. Vasal, A. Ortega and S. Pandey

INTRODUCTION

Maize plant lends itself to genetic improvement both by inbreeding and cross-breeding procedures. This provides alternatives to maize breeders to develop maize types that will fall in two broad categories. (1) Hybrid forms including single crosses, three-way crosses, double crosses, double top crosses and varietal hybrids; (2) Open-pollinated populations in the form of local or improved varieties belonging to particular races, broadbased composites, synthetics and advanced generation varietal crosses. Development and improvement of the above types of materials, however, involve different breeding approaches. In many developed countries of the world where private hybrid seed industry is well developed, hybrids are most commonly grown and these cover a large part of the total maize acreage. It is, therefore, implicit that in such countries the major research effort is geared towards the development of hybrid maize. Very little, if any, effort is going into population improvement. In contrast the situation in most developing countries is quite different. The private seed industry is either non-existent or so poorly developed that it can hardly do an effective job of seed production and distribution. Also, the spirit of cooperation between private and public sectors is lacking with the result that both are working in competition rather than for each other. A situation like this is not in the overall interest of the country. Difficulties in seed production and distribution have prevented these countries from taking up time consuming and expensive hybrid maize breeding programs. Breeding and improvement schemes designed to improve open-pollinated varieties and composites, therefore, seem to be the most logical approach for such countries at the moment. If such types are released the seed distribution will not be easy but will be greatly facilitated by seed movement from farmer to farmer. It is important to mention that such countries need not stick to this approach only. Any time enough competence and facilities are developed, the switch over to hybrid maize program can be made as quickly as possible.

It may seem important to point out that population improvement in maize is not completely divorced from hybrid maize development. Improvements made in maize population through various intra-population schemes can be profitably exploited in deriving new superior lines. As the genetic base of the material is continually improved, one would expect that the opportunities to extract new and better lines also become greater with every cycle of improvement. It is, therefore, desirable that even in those countries interested in hybrids, population improvement programs are basic to hybrid development to continue obtaining consistent gains in the long run. This is, however, not to argue or to present a case that better hybrids have not been developed in the past. On the contrary, it is very obvious that remarkable progress coupled with consistent gains over the years has taken place even without the use of classical population improvement schemes (Duvick, 1977). It is reported that much of the gains in the presently grown hybrids have been obtained from the improvement of established inbred lines through pedigree method of inbred improvement. Several other methods of inbred improvement have also been used and these are reviewed in a recent paper by Bauman (1977). Another interesting result reported in Duvick's study is that the gains from recurrent selection schemes in some synthetics from Iowa

Symposium on maize and peanut, Paramaribo,
Nov. 13 - 18, 1978

have also the same rate of genetic gain as obtained in resultant hybrids developed from inbred lines improved by the pedigree method.

Since I am going to talk on population improvement, I should probably re-emphasize that population improvement in maize, irrespective of objectives, is a must and it can play a dual role. Improvements made in populations through intra-population schemes not only improve the value of the population for direct and immediate use but also enhances its usefulness in giving rise to new lines as potential parents of hybrids. There is enough data already available to convince that population improvement should increase the expected performance of hybrids to a great extent rather than repeated sampling of the same base population in the classical inbreeding and hybridization approach. Many breeders are aware of the developments in recent years and hopefully there will be an increasing realization over time that a good balanced corn improvement program should place emphasis on the development and improvement of maize population or source germplasms in addition to development and improvement of inbred lines.

PAST ACCOMPLISHMENTS IN THE DEVELOPMENT OF POPULATION IMPROVEMENT METHODS IN MAIZE.

The development and improvement of maize populations has received considerable interest over the last two decades. Though earlier attempts to improve maize materials have been futile, the situation has changed considerably today. There is better understanding that failure to realize significant progress from earlier studies on mass selection could be due to insufficcient genetic control and field plot techniques.

Interest in quantitative genetics started developing in the 1940's. Since then voluminous data has been accumulated presenting accomplishments, both in theory and experimental results. Much of the renewed interest in improving populations has resulted from quantitative genetic studies in maize. The results of several empirical studies have indicated that there is a preponnderance of additive genetic variance for grain yield and other traits in heterozygous maize populations. Such results will suggest that various forms of intra-population schemes should be effective in improving the performance of maize populations. The developments in quantitative genetics have also helped maize breeders in understanding the types of gene action involved in the expression of different characters in maize that are under polygenic control. This type of information is of considerable importance for the breeder in making a choice among alternative breeding schemes. Another area where the quantitative geneticist has helped the breeder is in predicting reasonably well genetic gains from various types of selection schemes. Several studies have been conducted using different selection schemes and in most cases a good agreement has been found between predicted and realized gains. The results in such areas have been reviewed by Gardner (1976) and Eberhart (1976).

Regarding developments in population improvement methods, I plan to present only a cursary review. One of the simplest and oldest methods still being used in many experimental stations is the mass selection method. It exploits aditive gene effects and epistatic interactions involving only additive genetic effects. Several research workers have reported success with this method (Johnson 1963, Gardner 1961, 1973, 1976). Mass selection can be very effective for those characters that are highly heritable and which can be identified before flowering *(Helminthosporium turcicum,* Thrips, Fall armyworm, plant height, flowering, leaf angle and prolificacy). Effectiveness of mass selection in changing ear number (Paterniani, 1978) and leaf angle (Ariyanayagam et al 1974) has also been reported. An improvement over simple mass selection can be made by planting in grids as suggested by Gardner (1961).

Modified ear-to-row selection scheme suggested by Lonnquist (1964) has been used quite widely and effectively in many programs with great success. Several research workers have found interesting results with this scheme (Webel and Lonnquist, 1967, Paterniani, 1967). This selection scheme involves selection among rows based on yield trial data followed by selection within selected rows in the crossing block. This scheme permits completion of one cycle of selection in one year. A modification of this scheme has also been suggested. It uses two seasons instead of one. In the first season only half-sib progenies are yield evaluated. In the second season selected half-sibs using remnant seed are recombined in a crossing block. For male rows only bulk of selected half-sib families is used. The prediction equation for estimating gains for this modified scheme has been given by Compton and Comstock (1976). Two generations per cycle are required to complete this scheme and may result in genetic gains of about one and one-half times as much as the one generation per cycle scheme. An obvious advantage of this scheme involves planting of less number of rows. This would allow larger samples of each family to be grown thus resulting in an increase in the within-row selection intensity. The gains from within family selection can thus be increased.

Several recurrent selection schemes have been suggested as a result of quantitative genetic studies. These include recurrent selection for general combining ability (Jenkins, 1940) recurrent selection for specific combining ability (Hull, 1945) and reciprocal recurrent selection for both general and specific combining ability (Comstock et al. 1949). These recurrent selection schemes differ in the type of tester and the ultimate goal for which the developed material will be used. The critical differences in the schemes are also based on the nature of gene action involved in the populations under selection. These schemes are, however, similar in having successive cycles of selection and the recombination of the selected portion of the population. Especially where the aim is to improve populations, the use of above mentioned recurrent selection schemes may not be highly efficient. It is probable that much of the yield increases that have been reported with these methods are primarily results of additive effects (Sprague 1967). If this is so, it would appear more appropriate to exploit additive genetic effects through phenotypic recurrent selection or through various forms of family selection schemes without the use of the tester.

Various types of mating designs have been suggested by Comstock and Robinson (1952). The three genetic designs suggested by them are useful in estimating additive, dominance and average degree of dominance. Design I is particularly useful for maize and has been used quite frequently not only to work out genetic variances but also to identify best families for recombination and further improvement in a practical maize breeding program. There are several ways one can use this scheme in an on-going population improvement program.

Several family selection schemes have become quite popular in the last one decade. These include full-sib, half-sib and S_1 selection schemes. A combination of S_1 and half-sib systems can also be used for improvement of some traits but cannot be suggested as a general breeding method.

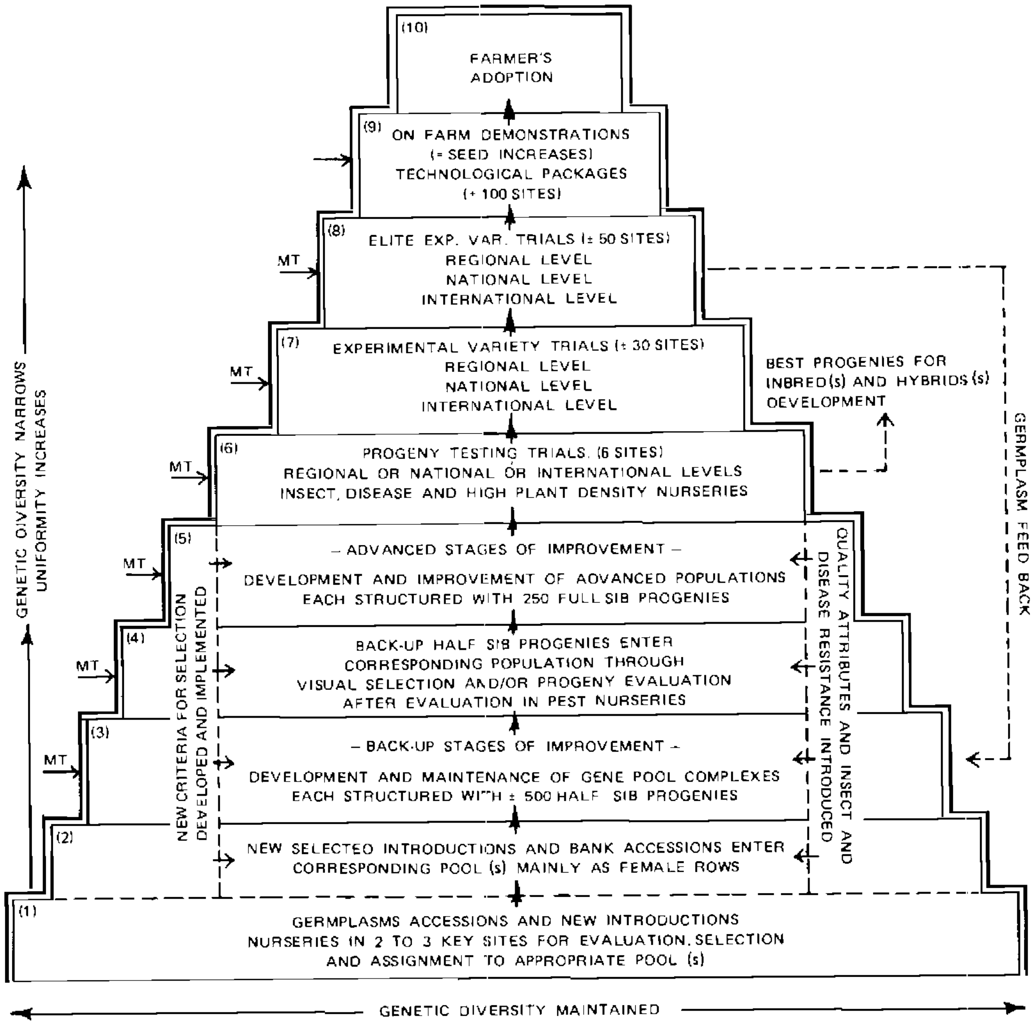
CIMMYT'S MAIZE IMPORVEMENT PROGRAM WITH GENE POOLS AND POPULATIONS

With the foregoing background I plan to devote the rest of the time in describing CIMMYT's maize program with particular emphasis on improvement of populations and development of experimental varieties both in normal and quality protein materials. I shall also touch very briefly on other aspects such as breeding for earliness, insect resistance, collaborative research, and quality protein that are receiving major emphasis in CIMMYT's maize improvement program.

CIMMYT's maize improvement program is a kind of multi-stage program with a continuous step-by-step flow of germplasm. The program believes very strongly in multi-disciplinary approach so that scientists from various disciplines can interact closely with each other on the improvement of various traits but within the same materials. The maize pyramid (fig. 1) illustrates management of maize germplasm at different stages of maize improvement until it reaches the hands of the farmers. CIMMYT's maize improvement program comprises of two main units namely the "Back-up" unit and "Advanced Unit" to handle research functions more appropriate to each unit. Quality protein versions of most materials are being developed through a side-car approach. Special projects have the responsibility of exploring and testing new research hypothesis before the information can be superimposed on the main research activities of the program.

It should be evident from fig. 1 that the back-up unit is a sort of supporting unit to provide superior genotypes or families to the advanced unit on a continuous basis so that improvements in advanced unit materials can be obtained from cycle to cycle. In this way, loss of genetic variability in advanced unit materials can be prevented. A similar type of approach was suggested by Harrison (1967). He suggested having back-up composites to support the composite undergoing population improvement with a high selection intensity. Suggestion was also made to use only mild selection intensity in back-up composites.

In the following section, the research functions within each unit are detailed.



MT: Multilocation Testing

A. Back-up Unit

The back-up unit handles the maize germplasm bank, new introductions and 34 gene pools that have specified climatic adaptation, maturity, grain color and texture.

The maize germplasm bank has close to 13,000 accessions representing 46 countries. It is a service unit for resident and outside scientists. The bank maintains germplasm collections and renews stocks from time to time depending on the seed viability. The seed stocks in the bank are catalogued. From time to time 400 collections are taken out and systematically evaluated at two or more locations with appropriate pools as checks. The best performers are grouped based on their adaptation, maturity, grain color and texture. In the following season the elite bank collections are incorporated into the corresponding pool only as a female for the first time. The crosses of the pools x collections can be observed separately for their combining ability and if

Table 1. Agroclimatic characteristics considered in classifying maize germplasm.

Maturity class	Altitude m.a.s.l.*	Latitude N-S	Temperature °C **			Days to physiological maturity
			Min.	Max.	Ave.	
Tropical lowland						
Early	below 1000 m	within 23°	22	32	28	± 80
Medium	below 1000 m	within 23°	22	32	28	± 100
Late	below 1000 m	within 23°	22	32	28	± 120
Tropical highland						
Early	above 1800 m	within 23°	7	22	16	± 150
Medium	above 1800 m	within 23°	7	22	16	± 180
Late	above 1800 m	within 23°	7	22	16	± 220 ***
Subtropical						
Early	below 1800 m	within 34°	17	32	25	± 100
Medium	below 1800 m	within 34°	17	32	25	± 130
Late	below 1800 m	within 34°	17	32	25	± 160
Temperate						
Early	below 500 m	outside 34°	14	24	20	± 110
Medium	below 500 m	outside 34°	14	24	20	± 130
Late	below 500 m	outside 34°	14	24	20	± 160

* Meters above sea level.

** Means of growing season.

*** South American Andean cultivars may take up to 13 months.

needed can be handled to F_2. Based on actual performance of topcrosses and also on judgement, the families from these crosses are later on merged with the main body of the pool.

The seed samples are sent to scientists and research organizations on request and free of cost.

Variety samples from the different national programs are brought personally by visiting CIMMYT staff members or are obtained by request from different sources. Once the samples are received, these are observed in observational nurseries at one or more locations. The good entries are identified and then systematically incorporated into the corresponding gene pool.

Gene Pools

CIMMYT maintains 34 gene pools to meet climatic requirements of tropical lowland, tropical highland and temperate-subtropical zones. (table 1) The pools within each climatic adaptation are further classified on the basis of maturity (early, intermediate, and late), grain color (white and yellow) and grain texture (flint and dent). Of 34 gene pools, twelve are meant for tropical lowland, fourteen for tropical highland and eight for temperate zone (table 2).

Gene pools are mass reservoirs of genes. They have broadbased genetic constitution as these have been formed by genetic mixing of several diverse varieties, variety crosses and hybrids with similar climatic adaptation, maturity, grain color and type.

Some important features in the handling of the pools are the following:

1. All gene pools are handled separately in isolation in a half-sib recombination system very similar to modified ear-to-row crossing block (Lonnquist, 1964). Several modifications to the commonly used half-sib system are, however, used in each pool depending on the priority and objectives that have been set for each pool.

Table 2. Cimmyt's gene pools and corresponding advanced maize populations, 1978

Back-up Stages				Advanced Stages	
Pool No.	Pool designation	Abreviation	Cycles of recombination and selection up to 1978	Corresponding Advanced Populations**	No.
Highland Pools					
1.	Highland early white flint	HEWF	C-5	–	
2.	Highland early white dent	HEWD	C-5	Blanco Dentado Precoz de Altura	52
3.	Highland early white floury	HEWFL	C-5	Blanco Harinoso Precoz de Altura	53
4.	Highland early yellow flint	HEYF	C-5	Amarillo Cristalino Precoz de Altura	54
5.	Highland early yellow dent	HEYD	C-5	Amarillo Dentado Precoz de Altura	55
6.	Highland intermediate white flint	HIWF	C-2	–	
7.	Highland intermediate white dent	HIWD	C-5	–	
8.	Highland intermediate white floury	HIWFL	C-5	Blanco Harinoso Intermedio de Altura	58
9.	Highland intermediate yellow flint	HIYF	C-5	–	
10.	Highland intermediate yellow dent	HIYD	C-5	Amarillo Dentado Intermedio de Altura	60
11.	Highland late white flint	HLWF	C-5	–	
12.	Highland late white dent	HLWD	C-5	–	
13.	Highland late yellow flint	HILYF	C-5	–	
14.	Highland late yellow dent	HLYD	C-5	–	
Tropical-subtropical pools					
15.	Tropical early white flint	TEWF	C-5	–	
16.	Tropical early white dent	TEWD	C-5	–	
17.	Tropical early yellow flint	TEYF	C-5	–	
18.	Tropical early yellow dent	TEYD	C-5	–	
19.	Tropical intermediate white flint	TIWF	C-8	–	
20.	Tropical intermediate white dent	TIWD	C-8	–	
21.	Tropical intermediate yellow flint	TIYF	C-8	Mezcla Amarilla; PD(MS) 6 H.E.o_2 ***	26, 38
22.	Tropical intermediate yellow dent	TIYD	C-8	Antigua x Republica Dominicana	35
23.	Tropical late white flint	TLWF	C-8	Blanco Cristalino 1; ETO Blanco; W.H.E. o_2	23; 32 40
24.	Tropical late white dent	TLWD	C-8	Tuxpeño 1; Mezcla Tropical Blanco; (Mix. 1 x Col. Gpo) ETO, Tuxpeño Caribe; La Posta, Tuxpeño o_2	21; 22; 25; 29; 43; 37
25.	Tropical late yellow flint	TLYF	C-8	Amarillo Cristalino 1; Y.H.E.o_2	27; 39
26.	Tropical late yellow dent	TLYD	C-8	Antigua x Veracruz 181; Amarillo Dentado; Cogollero	24; 28; 36
Temperate-subtropical pools					
27.	Temperate early white flint	TmEWF	C-8	–	
28.	Temperate early white dent	TmEWD	C-3	–	
29.	Temperate early yellow flint	TmEYF	C-4	Templado Amarillo o_2	41
30.	Temperate early yellow dent	TmEYD	C-4	Compuesto de Hungria	48
31.	Temperate intermediate white flint	TmIWF	C-4	Blanco Subtropical	34
32	Temperate intermediate white dent	TmIWD	C-8	AED X Tuxpeño	44
33.	Temperate intermediate yellow flint	TmIYF	C-8	Amarillo Subtropical	33
34	Temperate intermediate yellow dent	TmIYD	C-8	ETO x Illinois; Amarillo del Bajio	42; 45

* No. H.S. Prog. = No. of Half Sib Progenies

** 250 Full sibs in each Population

*** H.E. o_2 = Hard endosperm opaque

2. One cycle of recombination and improvement is completed each year in all highland pools. In tropical lowland and temperate pools, 2 cycles of selection are completed every year.

3. Fairly large population size is handled within each pool. The average number of families within each pool ranges from 400-500. Each family has 16 plants in a 5 m. long row. This gives a total number of female plants within each pool to 64,000-80,000 plants. Another 32,000 – 40,000 plants constitute male plants from the same families. This gives an effective population size of about 96,000 to 120,000 plants within each pool.

4. In all gene pools, the ratio of females to males is kept at 2 to 1 in the recombination block. Both male and female rows are planted at the same time. If needed the male rows can be staggered at different dates to permit thorough mixing within the pool.

5. The male and female rows are usually planted at the same density. However, in some pools, the males are planted at double the density than the females to permit either better expression of the trait (interval between pollen shedding and silking, barrenness) or when pools are subjected to some stress conditions (infestation by cogollero and borers) so that all undesirable plants can be eliminated before pollen shedding without affecting plant stand very much.

6. Once every year the half-sib families from each pool are planted at least at two locations within Mexico to select for broader adaptation.

7. Selection is practiced both in male and female rows. In male rows all tall, diseased and undesirable plants are detasseled before pollen shedding. In this way selection pressure can be exerted in male rows for those characters that can be visually seen before or at the time of flowering. Detasseling undesirable plants in male rows prevents dissemination of pollen from inferior plants to pollinate plants in female rows.

8. Between and within family selection is practiced within each pool at different stages of development.

9. In female rows, the families can be rejected on the basis of family performance. In desirable or selected families, the superior plants within each family can be marked at different stages depending upon special objectives in the pools. Rechecking and marking good plants within each selected family is done in all pools, 2 or 3 weeks prior to harvesting.

10. In all early pools where we are interested in moving the maturity still on the earlier side, tassels from the male rows are removed following 50-60% silking in female rows. This is a good procedure that permits self-elimination of all late families within the pool.

11. Different pools are subjected to different stress pressures depending upon their use in different areas. To name a few of these stress pressures, two pools (19 and 21) are being subjected to borer infestation *(Diatraea saccharalis);* two pools (24, 26) to infestation by cogollero *(Spodoptera frugiperda);* two pools (30, 32) to another species of borers *(D. grandiosella);* pool 3 to corn earworm *(Heliothis zea);* two pools (23, 25) to stalk rots; and four pools (20, 22, 33, 34) to ear rots.

12. Mild selection intensity is practiced within each pool to prevent depletion of attributes or genes necessary for further advance at some later stage. Lower selection intensity also provides better chance and opportunities for recombination among linked genes which with higher selection intensity will probably be thrown out much earlier. Between family selection of about 50-60% and within family selection in selected families of 6-18% is practiced.

13. At harvest the selected ears from selected families are grouped as male and female ears. The male ears are selected out of very good plants. While in the forthcoming cycle all selected ears, both males as well as females enter as separate families, the male rows are planted with a balanced male composite made up only from selected male ears.

14. In all gene pools, where one or the other stress pressure is being exerted, the ears from the selected plants are grouped and planted to follow some sort of sequence within the main body of the pool. Next time, when these pools are subjected to the same stress conditions, one can make relative comparisons of the families selected from desirable and undesirable plants for this particular trait.

15. Improvements or changes affected in each pool from cycle to cycle can be checked rather easily without much effort by planting two or more rows of each cycle of selection with or without replications at the end of each pool.

16. While gene pools are being improved for superior traits, all possible care is taken to maintain genetic diversity within each pool. This would mean that families or plants not good for stress traits but otherwise good in agronomic traits are saved and used in the next cycle of recombination.

17. New additions from the bank or from the introduction nursery can be added as female rows in the pool. Based on judgment or through further observation or by advancing a generation or two, the families from the cross can be rejected either completely or made part and parcel of the main pool body. New additions permit continuous broadening of the pool.

18. Gene pools corresponding to all advanced unit populations have been developed and are available. The opposite is however, not true. All gene pools do not have corresponding advanced unit populations. Also some gene pools may have one or more corresponding advanced unit populations to support.

19. Advanced unit populations are planted periodically as check entries within each pool to identify superior families for further evaluation and incorporation in the advanced unit population.

20. To obtain quality protein versions of each pool, a bulk of stable hard endosperm opaque-2 families can be planted at the end of each pool as female rows for making backcross once in every 3 or 4 cycles.

21. Bulks from various pools are also sent to different regions where CIMMYT staff members are stationed. Ears saved from each location are brought back to Mexico for inclusion in the pool. This way we introduce potential influence of other environments into the pool.

From the foregoing, it is clear that while pools are being recombined and improved continuously, they are also being broadened regularly with the addition of new introductions from the national programs and with superior matching entries from the maize germplasm bank.

B. Advanced Unit

The advanced unit deals with both normals and quality protein maize populations. Presently the unit is handling 24 populations of which five carry opaque-2 gene. These populations have been chosen because most of these materials have been improved for several cycles for yield, plant height, diseases and other traits. It is, therefore, expected that some of these materials may be of more immediate and direct use to some of the national programs. However, it may be important to mention that whenever any material is advanced or considered for inclusion in the advanced unit several criteria are examined. These are 1) evaluation of the material in some variety test in different countries, 2) based on variety test performance, the progeny tests are also sent to those places where this material may have some potential or role to play, 3) In certain cases the decision is also based on experience depending upon the type of germplasm involved in the genetic constitution of the population. For many populations, it is possible to predict reasonably well the areas or regions of their adaptation.

The advanced unit materials are handled in full-sib family selection scheme. Each population is structured on family basis with 250 full-sibs. In each advanced unit population one cycle of selection is completed in two years. Though it is possible to complete one cycle of selection in one year, non-retrieval of data from all the locations in time prevent us from doing so. Since families from each population are sent to northern as well as southern hemispheres, there is no way of getting data in time from all the locations. One would argue that this results in slow progress. This is true but to compensate for this slow progress we have worked out a system by which the time available between two cycles can be utilized more efficiently and effectively by improving those traits in which these populations are most deficient. In the full-sib family selection improvement the following steps are involved:

a. Population Improvement

1. *Progeny regeneration:* 250 full-sibs are developed from each population through reciprocal plant to plant crosses among families. This is done to obtain enough seed to use in subsequent operations once a family is identified as a good performer. In quality protein populations only those pairs are saved that have both members in a pair well modified with respect to endosperm hardness.

2. *Progeny tests:* 250 full-sibs plus six checks are sent out to six different countries for evaluation in 16x16 simple lattice with two replications.

3. *Family improvement:*

   i. In the following season all 250 families are planted. Within family selection is practiced for the character in which it is most deficient. If before pollination data becomes available from some locations a preliminary selection can be practiced to save about 50% of the families. In such an instance within family selection will be restricted to selected families.

   ii. Either selfs or plant-to-plant sibs are made within each family to keep the identity of the family. For characters such as earliness and plant height which can be seen before or at the time of flowering, within family sibs are usually made. In opaque-2 populations where we are interested in selecting better modifiers, plant to plant sibs within each family are made in a reciprocal fashion. In other characters where the expression can be best judged at harvest time, either selfs or reciprocal plant to plant crosses are made within each family.

   iii. At harvest, on the average 3 sibs or 3 selfs are usually saved from each family.

   iv. The sibs or selfs saved from each family are again planted in the next season. Full record is kept of all sub-families originating from their parental family. Generally, before making this planting, data arrives from all locations. It is, therefore, possible to finalize families that are best performers on the basis of across location data. In such an instance only the selfs or sibs from selected families will be planted.

Selection is again practiced for the same trait both between and within sub-families of a given parental family. Better family/families and better individuals within the selected sub-families of each parental family or set are marked and bulk-pollinated in a hand-pollinated half-sib fashion.

On the average 2 or 3 half-sibs are selected uniformly from each original parental full sib family that was selected on across location performance.

The selected half-sib ears are again planted on ear-to-row basis. A record is kept of all half-sibs originating from the parental full sib families. Reciprocal plant to plant crosses are made among half-sib families originating from different parental full-sib families. Again at harvest 250 full-sib pairs are saved to continue the next cycle of selection.

It may be important to mention that a selection intensity of 30-35% is used in each population. The gains resulting from each cycle of selection in some populations are given in table 3.

Table 3. Actual gains in some advanced unit populations undergoing full-sib family population improvement (across location data).

Population	Gains Per Cycle		
	Grain Yield (%)	50% Silking	Plant Height (cm)
Tuxpeño-1	3.2	-0.3	-3
Mezcla tropical blanca	2.5	-0.5	-2
Mix. 1-col. GPO. 1 x ETO	5.7	-0.5	-2
Mezcla amarilla	4.4	-1.0	0
Amarillo cristalino	3.0	-0.3	0
Amarillo dentado	2.5	0.0	+2
Tuxpeño caribe	5.4	-0.7	+3
ETO blanco	4.4	-1.3	-6
Cogollero	9.1	-1.0	+2
La Posta	3.8	-0.7	-3

b. Development of Experimental Varieties

In the development of experimental varieties, a very high selection intensity of 2.5% is used. The experimental varieties are developed on the basis of site specific and across site progeny test data. Thus each population has a potential of giving rise to seven experimental varieties (6 site specific and one across site experimental variety). Since the best fraction of each population is taken out to form the experimental variety, one would expect considerably higher genetic gains over the population mean for immediate use and exploitation. In the selection of 10 best families, high yielding families with relatively uniform agronomic attributes are recombined so that the variety may look fairly uniform.

In the formation of experimental varieties diallel matings are made among 10 families. Also at this stage relatively uniform looking plants are used in recombination. From a recombination of 10 families adequate seed is obtained to conduct at least 40 experimental variety trials. A balanced bulk of saved ears goes into a second order seed increase to build up enough seed quantity for each experimental variety. This helps to include the variety into elite experimental variety trial if it turns out to be good in EVT trial.

The experimental varieties are named in such a way that cooperators from different national programs who actually conduct the progeny tests get full recognition. The varieties carry the name of the station where the progeny test was conducted. This is followed by two digits indicating the year. The last two figures show the population number (e.g. Ticuman 7428).

c. Experimental Variety Trials

The site specific and across site experimental varieties are developed on the basis of progeny trial data as mentioned earlier. The experimental varieties so formed from different populations are grouped into different experimental variety trials 11 through 17. Trial 15 is reserved for experimental varieties derived from advanced unit opaque-2 populations. Each experimental variety trial is sent out between 30 to 40 locations. The best performing experimental varieties across locations are promoted to elite experimental variety trials. From the data presented in tables 4 and 5, it can be seen that a number of experimental varieties were quite superior compared to the parental population.

Table 4. Comparison of performance of experimental varieties and their parental population.

Experimental variety	Parental population	Grain Yield (kg/ha.)		Experimental variety yield as percent of parent population
		expt. variety	parental population	
Gemiza 7421	Tuxpeño-1	4456	3965	112.4
Poza Rica 7429	Tuxpeño Caribe-2	4235	4683	110.5
Obregon 7431	Braquiticos	4066	3266	124.4
Across 7443	La Posta	4865	4184	116.2
Sids 7444	A.E.D. x Tuxpeño	4166	3370	123.6

Table 5. Comparison of performance of experimental varieties and their parental opaque-2 populations.

Experimental variety	Parental population	Grain expt. variety	Yield kg/ha. Parental population	Experimental variety Yield as percent of Parent population
Gemiza 7437	Tuxpeño o_2	4539	3343	135.7
Poza Rica 7437	"	4505	3343	134.7
Obregon 7437	"	4429	3343	132.4
Across 7437	"	4563	3343	136.4
DELHI 7439	Yellow H.E.o_2	4272	3410	125.2
Poza Rica 7439	"	4374	3410	128.2
Cuyuta 7441	Composite K H.E.o_2	4363	3685	118.3
Poza Rica 7441	"	4446	3685	120.6
Delhi 7438	(Ver. 181 x Ant. Gpo. 2)x Ven. 1 o_2	4060	3449	117.7
Poza Rica 7438	"	4041	3449	117.1
San Andres 7440	White H.E.o_2	4274	3863	110.6

d. Elite Experimental Variety Trials

The best performing experimental varieties form the elite experimental variety trial. Elite experimental variety trials carry trial numbers from 18 through 20. ELVT's 18, 19, and 20 are reserved for tropical lowland, opaques and temperate-subtropical materials, respectively. The elite experimental variety trials are sent to more than 50 locations around the world. The number of trials sent to different countries during the last four years are presented in table 6.

Table 6. Number of experimental variety trials distributed during different years.

Trial Name	No. of trials sent to dif. country			
	1975	1976	1977	1978
OMPT-11	20*	–	–	44
EVT-12	25	27	31	38
EVT-13	24	27	34	45
EVT-14A	36	33	48	61
EVT-14B	–	34	40	42
EVT-15	27	15	38	36
EVT-16	32	21	35	49
EVT-17	15	16	–	17
ELVT-18	–	73	78	91
ELVT-19	–	60	54	52
ELVT-20	–	40	47	56
	180	367	405	531

e. Off-Station trials and Farmer's adoption

Good performing elite experimental varieties in national programs can be tested in off-station trials. Following verification on a big sized plot the variety can be made available to the farmer.

C. Breeding for earliness

Early maize varieties are needed in many parts of the world either to fit into the cropping pattern or make full use of the growing season because of a particular rainfall pattern. In general very early materials are very susceptible to foliar diseases and have very low yield potential even under reasonably high plant population density. Over the past four years, CIMMYT has placed major emphasis on developing early genotypes for tropical, temperate and highland areas. The following four approaches are being tried at CIMMYT to develop early materials.

1. Recurrent selection for earliness in a full season maize composite.

2. Crossing early types with mid to full season materials followed by selection for earliness along with other desirable agronomic characteristics.

3. Intercrossing among early types followed by selection for yield and foliar diseases without sacrificing earliness.

4. Intercrossing early tropical maize with corn belt maize with the objective of combining yield, earliness and resistance to foliar diseases.

As regards the first approach, about 400-500 half-sib families are being handled in an early composite using half-sib selection program. Early plants are marked in the families and as soon as 60-70% of the families have silked, tassels are removed from the male rows to eliminate the late fraction of the population. The material is then harvested somewhat earlier to make visual separation of the drier ears. Only good ears from good early plants and relatively more drier are selected for continuation in the next cycle.

The same approach is being used in some pools except that the experimental material has resulted from the crosses of early composites with full to mid season advanced unit maize populations.

From the first two approaches it seems that it is possible to make materials one day earlier each cycle while maintaining more or less the same yield level. The last two approaches are also underway though no evaluation for progress has yet been made.

The results of full-sib family selection for earliness in some advanced unit materials are presented in table 3. It is clear from the table that in many populations maturity has been reduced with the same or increased level of yield.

D. Development of maize populations resistant to downy mildew, stunt and streak.

Breeding for resistance to above diseases is being handled in CIMMYT's collaborative research program. These three diseases already exist and pose potential danger to many maize growing areas of the world. The streak virus is limited to Africa, downy mildew to Asia and stunt to Central America and Mexico. The occurrence of downy mildew has also been reported from Central America, South America and Africa. Materials possessing resistance to each of these problems singly or in combination to each other thus seem very important.

Since resistance to all three diseases cannot be selected effectively in Mexico, we are collaborating with several national programs which are "Hot Spots" for these diseases. We have chosen three broadbased agronomically superior maize populations that have different grain color and type and can be grown satisfactorily in many parts of the world. We are collaborating with El Salvador and Nicaragua to select against stunt. Artificial inoculations can also be done in Mexico to screen for stunt resistance. The work on downy mildew screening is done in Thailand and Philippines while the streak work is restricted to three African countries namely Tanzania, Nigeria and Zaire.

Though the materials have gone through 3-4 cycles of selection, satisfactory levels of resistance have already been built up in all three populations at least to downy mildew and stunt. Combined resistance to stunt and downy mildew has also been built up in three subpopulations of the same three materials though the progress has been somewhat slow.

Downy mildew resistance is also being incorporated into five advanced unit materials through backcrossing program. Segregating generations are screened in Thailand. In due course of time we hope to have resistance in these five populations.

E. Breeding for insect resistance

Breeding insect resistant materials require mass rearing and artificial infestation facilities. To meet this need, an insect rearing laboratory has been established at CIMMYT's premises for the last three years. The laboratory is functioning remarkably well. The rearing of insects can be done for several insect-species such as cogollero *(Spodoptera frugiperda)*, borers *(Diatraea saccharalis* and *D. grandiosella)*, and corn earworm *(Heliothis zea)*.

Enough egg masses can be produced in all these insect species to artificially infest all maize populations that are ear marked for insect resistance work.

The artificial insect infestation technique needs special mention. It is a remarkable improvement over what entomologists have been doing in the past. The new technique uses young hatched larvae instead of egg masses. The egg masses that have just hatched in the laboratory are mixed with ground corn cob grits. This mixture is applied in maize whorl with the help of a "bazooka". In different insects this mixture is applied at different stages of leaf development. This technique works very well for cogollero and borers. The same technique also works well for corn earworm except that the mixture is applied on the silks of the maize ear. This new technique has considerably speeded up insect resistant work at CIMMYT. It has many advantages such as convenience of handling larvae mixture both in the laboratory and in the field, 3-4 times faster, more uniform infestation and less frequency of escape plants.

Various pools and advanced unit populations are being selected for resistance to these insects as mentioned earlier in the text.

From whatever little work has been done at CIMMYT, it seems that there is enough variation in pools and populations to accumulate favorable resistant alleles in maize materials.

F. Breeding for quality protein maize

Quality protein versions of most materials in the advanced and back-up stages of the maize improvement program have been developed through the incorporation of opaque-2 gene. As is well known, the opaque-2 materials suffer from the following problems:

1. Low grain yield
2. Unacceptable soft chalky appearance
3. More vulnerable to ear rots and stored grain pests
4. Slower drying following physiological maturity of the grain

The major emphasis in the quality protein program has been placed on solving the above problems which have acted as the major hurdle in the commercial acceptance of opaque-2 materials. The research strategy used at CIMMYT has concentrated on accumulation of genetic modifiers to solve the problems. Through the use of modifiers it is possible to change the phenotype of opaques from soft to completely normal looking phenotype. In accumulating modifiers one faces several difficulties. In the first place the protein quality tends to decline with the selection of vitreous kernels. Exceptions, however, occur and these should be exploited to accumulate favorable modifiers to develop hard endosperm opaque-2 materials without sacrificing protein quality (table 7). Another problem associated with the selection of modifiers is

Table 7. Protein, lysine and tryptophan in the whole grain of some promising hard endosperm opaque-2 materials

Material	Protein (%)	Lysine in protein (%)	Tryptophan in protein (%)
PD (MS) 6 H.E. o_2	10.8	3.4	0.83
Amarillo dentado H.E.o_2	11.2	3.5	0.88
CIMMYT H.E. o_2	10.9	3.8	0.97
White opaque-2 Back-up Pool	10.4	3.5	0.89
Ant. x Ver. 181 H.E. o_2	11.2	3.6	1.00
Temperate x tropical H.E. o_2	9.2	3.8	1.12

the instability of modifiers under different environmental conditions. Experience gained at CIMMYT seems to show that it is possible to stabilize modifiers by following 6-7 cycles of selection. Once the materials have attained a fairly high frequency of modifiers, it has been observed that the majority of the families over environments appear to be stable (table 8). It is, therefore, suggested that one should not talk about the stability of the modifiers until the material has gone through enough cycles of selection and that variation for hard endosperm opaque-2 character within the population has been reduced to minimum.

Table 8. Frequency of difference in endosperm hardness ratings of opaque-2 families from different populations grown at three locations during the year 1977.

Population No.	Population	Frequency of difference in endosperm hardness ratings of fam.								Total No. of families
		0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	
38*	PD (MS) 6 H.E.o_2	64	125	45	14	1	1	–	–	250
39	Yellow H.E.o_2	25	119	68	35	2	1	–	–	250
40	White H.E.o_2	20	107	71	44	8	–	–	–	250

* Two locations only.

At CIMMYT the hard endosperm opaque-2 versions of advanced and back-up materials have been developed. In addition four tropical opaque-2 back-up pools, 3 temperate back-up pools and three high-land back-up pools have been developed. The opaque-2 back-up pools are handled more or less the same way as the normal pools except some additional attributes such as selection of modifiers, maintenance of protein quality, stability of hard endosperm opaque-2 character, and reduced ear rot incidence are given high priority in selection in addition to several agronomic attributes. The performance of some of the opaque-2 materials is given in tables 9 and 10. It can be seen that some opaque-2 materials have yield levels equivalent to that of normals.

Table 9. Results of EVT 15 during 1977 – mean across 14 locations.

Entry No.	Pedigree	Grain yield (kg/ha)	% of best check
1	Ferke 7537	5005	104
2	Cotaxtla 7537	3837	100
3	CIMMYT H.E.o_2	3534	92
4	Ferke 7539	3659	95
5	Suwan 7539	3690	96
6	Poza Rica 7539	3510	91
7	Ant. x Ver. 181 H.E.o_2	3728	97
8	Poza Rica 7540	3232	84
9	Across 7437	3551	92
10	Best Check mean	3833	100

Table 10. Performance of best opaque against normal check, EVT-15 – Year 1977

Location	Grain yield (kg/ha.)	
	Best opaque	Normal Check
San Jeronimo (Guatemala)	5030	3644
Panama	2903	2649
Obregon (Mexico)	2297	1491
Costa Rica	3479	2903
Cotaxtla (Mexico)	4400	3855
Ludhiana (India)	6036	5549
Pirsabak (Pakistan)	4394	2742
Nicaragua	3946	4409
El Salvador	3394	3958
Jamaica	2864	3761
Suwan (Thailand)	5611	6692

REFERENCES

Ariyanayagam, R.P., C.L. Moore, and V.R. Carangal, 1974. Selection for leaf angle in maize and its effect on grain yield and other characters. Crop Sci. 1974: 551-556.

Bauman, L.F., 1977. Improvement of established maize inbreds. Maydica XXII: 213-222.

Compton, W.A. and R.E. Comstock, 1976. More on modified ear-to-row selection in corn. Crop Sci. 16: p. 122.

Comstock, R.E. and H.F. Robinson, 1952. Estimation of average dominance of genes. In Heterosis, Iowa State College press, Ames, Iowa pp. 494-516.

Comstock, R.E., Robinson, H.F. and Harvey, P.H., 1949. A procedure designed to make maximum use of both general and specific combining ability. Agron. Jour. 41:360-367.

Duvick, D.N., 1977. Genetic rates of gain in hybrid maize yields during the past 40 years. Maydica XXII: 187-196.

Eberhart, S.A., 1976. Practical genetics and practical corn breeding. In Proc. of the International Conference on Quantitative Genetics, Iowa State University Press, Ames, Iowa: 491-502.

Gardner, C.O., 1961. An evaluation of effects of mass selection and seed irradiation with thermal neutrons on yield of corn. Crop Sci. 1: 241-245.

Gardner, C.O., 1973. Evaluation of mass selection and of seed irradiation with mass selection for population improvement in maize. Genetics 74: 588-589.

Gardner, C.O., 1976. Quantitative genetic studies and population improvement in maize and sorghum. In Proc. of the International Conference on Quantitative Genetics, Iowa State University Press, Ames, Iowa: 475-489.

Harrison, M.N., 1967. Selection of source material and methods of formation of composites for maize breeding. Paper presented at Eastern African Cereals Research Conference.

Hull, F.H., 1945. Recurrent selection and specific combining in corn. A. Amar. Soc. Agron. 37:134-145.

Jenkins, M.T., 1940. The segregation of genes affecting yield of grain in maize. J. Amar. Soc. Agron. 32:55-63.

Johnson, E.C., 1963. Mass selection for yield in a tropical corn variety. Amer. Soc. Agron. Abst. pp. 82

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

Paterniani, E., 1967. Selection among and within half-sib families in a Brazilian population of maize. Crop Sci. 7:212-216.

Paterniani, E., 1978. Phenotypic recurrent selection for prolificacy in maize. Maydica XXIII: 29-34.

Sprague, G.F., 1967. Quantitative genetics in plant improvement. In plant breeding edited by K.J. Frey: 315-354.

Webel, O.D. and J.H. Lonnquist, 1967. An evaluation of the modified ear-to-row selection in a population of corn. Crop Sci. 7:651-655.