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INBRED LINE EVALUATION NURSERIES AND THEIR ROLE IN MAIZE BREEDING AT CIMMYT[1]

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ABSTRACT - CIMMYT initiated its hybrid maize (*Zea mays* L.) research program in 1985 in response to the growing needs of the national programs for hybrid-oriented source germplasm. Since 1991 CIMMYT has released a total of 424 inbreds that are widely distributed and used by public and private sector researchers around the world. Inbred line evaluation nurseries are an important component of a hybrid research program. At CIMMYT, we routinely evaluate inbreds for various biotic and abiotic stresses, their yield potential and other agronomic attributes. We have been successful in identifying several lines for specific stresses, although they were not selected during the development process which can be attributed to the genetic diversity of CIMMYT's source germplasm. Some of the abiotic stresses for which we have identified resistant/tolerant lines are: drought, low-N use efficiency, and acid-soils. For biotic stresses we have identified resistant lines for fusarium ear/stalk rot, banded leaf and sheath blight (*Rhizoctonia spp.*), tar spot (*Phyllachora maydis*), grey leaf spot (*Cercospora zeae-maydis*), rust (*Puccnia polysora*), maize streak virus (MSV), fall armyworm (*Spodoptera frugiperda*), sugarcane borer (*Diatraea saccharalis*) and striga. Lines with above average general combining ability and yield stability have been identified. These lines are available for public use.

KEY WORDS: *Zea mays*: Inbred nurseries, Biotic and abiotic stress; CIMMYT Maize Lines.

INTRODUCTION

Maize breeding methods and priorities for research have continuously evolved at the International Maize and Wheat Improvement Center (CIMMYT) since its inception in the mid-sixties. Until the mid-80s, CIMMYT's major thrust was on population improvement. During this time intrapopulation improvement methods were emphasized in germplasm at different levels of development and improvement process. Mostly non-inbred progenies, either full-sibs or half-sibs, were test evaluated in on-going recurrent selection programs. The year 1985 marked the beginning of hybrid research and inbred line development program at CIMMYT. A number of initiatives were started on a modest scale to include such activities as interpopulation improvement programs, emphasis on hybrid-oriented source germplasm, research on non-conventional maize hybrids and more importantly training. Conscious and concerted efforts were made to integrate population improvement and hybrid research activities so that both approaches were mutually benefitted. The program made first announcement of maize inbreds in 1991. A total of 139 lines were announced from a wide range of germplasm sources to accelerate hybrid research activities in the developing world. A systematic testing of maize hybrids in international trials began in 1994 and has led to expanded research efforts since then.

CIMMYT maize researchers have recognized the importance of inbreeding as an important tool. Though little or no inbreeding was practiced in the mid-seventies, a beginning in this direction was introduced in 1978 as part of on-going population improvement efforts. Mild inbreeding involving one or two generations of selfing was introduced in population improvement as part of intra-family improvement. Inbreeding beyond S2 was started only after the initiation of hybrid maize program in 1985. Using good performing lines, several inbreeding stress-tolerant synthetics were developed and registered (Vasal *et al.*, 1995). Evaluation of inbred lines for combining ability started soon after the initiation of hybrid program. The results from the first set of diallels conducted in 1986-87 were published by Han *et al.* (1991). Conscious ef-

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forts in identifying testers were made as early as 1987 that led to several line x tester studies (VASAL *et al.*, 1992a, 1992b). Based on heterotic pattern information, new heterotic groups were formed. Also potentially useful inbreds were registered (VASAL *et al.*, 1997a, 1997b). Following the first annoucement of inbreds in 1991, 424 CMLs have been released.

Inbred development and evaluation constitute the more important steps in hybrid research. Inbred evaluation is done to obtain combining ability information in hybrid combinations and for per se performance for yield and other agronomic traits. Evaluating inbreds for combining ability is universally practiced by all maize breeders in selecting lines of high yielding hybrid combinations. The other aspect of inbred evaluation for per se performance is not as common as it should be because of previous studies and published information that there is a poor correlation between the per se and the hybrid performance (NILSSON-LEISSNER, 1927; JORGENSON and BREWBAKER, 1927; JOHNSON and HAYES, 1936; HAYES and JOHNSON, 1939; JENKINS, 1929; GAMA and HALLAUER, 1977). With this notion most researchers often overemphasize combining ability evaluation and per se evaluation receives little or no research emphasis. Both types of evaluation are important and play a key role in identifying superior maize hybrids and determine economics of hybrid maize seed production. With shifting trend towards two-parent single crosses, the latter aspect has gained increasing importance in the past two to three decades.

RELEVANCE AND USEFULNESS OF INBRED LINE EVALUATION NURSERIES

Evaluation nurseries provide useful information on several aspects and help increase the database for each inbred. Some of the advantages and/or objectives for conducting such nurseries include the following:

1. Provide information on agronomic performance of inbreds for yield and other important traits.
2. Stability of performance in specific locations and across-locations.
3. Evaluate merits and demerits of each line for a given trait.
4. Evaluate lines for traits and stresses not screened previously.
5. Choosing partners and systematizing inbred recycling process.
6. Formulating crossing programs and schedules more precisely with available data.
7. Identify inbreds for their value as either pollen or seed parents.
8. Compile information on inbreds for use by public and private breeders.
9. Provide information on comparative performance of inbreds developed from different germplasm types and inbred line development techniques and methods.
10. Integrate multidisciplinary activities.
11. Selection of germplasm for special inheritance studies and biotechnology studies.
12. Improve communication and interaction among scientists with a common goal.
13. Study reliability of disease inoculations and insect infestation techniques.
14. Identify donor inbreds for various traits.
15. Study behavior of inbreds under general and specific stresses.
16. Vehicle for dissemination of inbred base germplasm.
17. Assists in the monitoring for either presence or absence of disease pathogens.
18. Identify rare allele(s) not identifiable at the population level.
19. Reduce the monotony of secretive efforts in hybrid maize research.
20. Integrates either awareness or perception of a good inbred phenotype.
21. Strengthen data base and resource inbred base germplasm for current and future needs.
22. Inbred line evaluation nurseries also provide useful basic information when conducted under stress and non-stress environments.
23. For traits that are complex, difficult, and lack genetic information, inbred evaluation nurseries are preferred over population improvement schemes in terms of efficiency, cost effectiveness, and rapid and repeatable results.
24. Strengthening inbred base resource germplasm and screening inbreds in evaluation nurseries seems to be sound strategy for studying multiple problems as opposed to population improvement approach requiring more resources and several independent programs to handle different traits. This approach is being used in Asian Regional Maize Program to build up resistance to several biotic and abiotic stresses.

Apart from CIMMYT, several other researchers have distributed systematic inbred line evaluation nurseries at the international level (BREWBAKER *et al.*, 1991; KIM *et al.*, 1988). These researchers studied resistance of tropically adapted maize inbreds of high combining ability through distribution of maize inbred resistance (MIR) trials internationally to collaborators for general tolerance/resistance to virus and virus like diseases. Interesting results have been reported. A relatively high proportion of the inbreds showed high or moderate resistance to MDMV-A (49%), MMV (42%) and SCMV-MB (33%) while fewer were resistant to corn stunt (23%) and maize streak virus (MSV) (17%). The MIR project has also studied and reported results of resistance of maize inbred lines to insects, diseases and parasitic weeds (KIM *et al.*, 1988).

TYPES OF INBRED EVALUATION NURSERIES

Several different types of inbred line evaluation nurseries or trials are conducted with some specific objective(s) in mind. Some of the types commonly practiced inbred line evaluation nurseries in CIMMYT's maize breeding program are described below.

1. Inbred evaluation nurseries may be part of on-going population improvement efforts. This category includes selfed progeny selection schemes involving either S1 or S2 of intrapopulation selection methods. The selfed progenies are tested in different locations and based on the performance tests, the superior progenies are intermated to complete a cycle of selection.
2. Several recurrent selection schemes emphasize general combining ability (GCA) (JENKINS, 1940), recurrent selection for specific combining ability (SCA) (HULL, 1945), and reciprocal recurrent for GCA and SCA (COMSTOCK *et al.*, 1949). Such schemes can be modified in several different ways to integrate with line per se performance so that both sets of data from combining ability and per se performance are considered to select selfed progenies for the next cycle of recombination. Modifications of such interpopulation schemes are already in place at CIMMYT.
3. Inbreeding-cum observational nurseries are practiced by several CIMMYT researchers during the inbred development process. Part of the row is left for observation and the remaining for self pollinations. Data recording is done only in the observation part. Ears are also harvested and rated for different traits. Only self-pollinated ears are saved from the selected rows.
4. Inbred evaluation-cum-topcross formation nurseries are also used by CIMMYT researchers. This procedure can be practiced in any selection scheme(s) where topcrosses are formed on S1 or S2 selfed progenies. Generally more number of selfed progenies are planted and topcross/testcross seed is saved from those selfed progenies which have good per se performance. This method can be followed in several breeding schemes including recurrent selection for GCA (JENKINS, 1940), for SCA (HULL, 1945) and for GCA and SCA (COMSTOCK *et al.*, 1949).
5. Companion nurseries of selfed progenies are planted to evaluate for diseases, insects, and crowding stress in addition to testcross performance in multilocation trials.
6. Selfed progeny evaluation are part of multistage progeny development process. Modification of several recurrent selection schemes require multiple stages in the progeny development process. Different sets of selection pressures can be exerted at different stages during progeny development. CIMMYT researchers are practicing selection for high plant density and drought tolerance during different stages of the progeny development of modified reciprocal recurrent selection schemes.
7. Evaluation of pre-screened agronomically superior early generation lines for various stresses is also practiced. In this option selfed progenies, preferably at S2 inbreeding level, are evaluated followed by evaluation of a selected sample of lines for drought tolerance and for other traits. This procedure has been successfully deployed in the improvement of gene pools where a combination of S2 and half-sib procedure is used.
8. Inbred evaluation nurseries are also conducted for specific traits. Promising inbreds at S4 or later generations that have survived inbreeding and have good combining ability can be evaluated for specific traits as follows:
   - Biotic stresses-downy mildew (DM), maize streak virus (MSV), foliar diseases and ear rots.
   - Abiotic stresses-drought tolerance, low nitrogen, acid soil tolerance, soil toxcity, salinity, and water logging.
   - General stress-tolerance to higher plant population density.
9. Multilocation inbred evaluation trials are also conducted to gain information on the performance and adaptation of lines in different sites. Useful data have been accumulated by CIMMYT researchers at headquarter through such inbred evaluation trials.

SOME SIGNIFICANT RESULTS AND ACHIEVEMENTS

Different types of inbred line evaluation nurseries have been conducted by CIMMYT researchers over the past few years. These nurseries or trials were designed for different purposes. Some of these trials were conducted in multilocations in natural field conditions whereas the others were conducted under artificial conditions either for abiotic or for biotic stresses. In this section a series of studies that have generated useful information and have identified specific maize inbred lines as useful sources of resistance to several abiotic and biotic stresses are described.

Yield and agronomic performance of CIMMYT maize lines

CIMMYT maize researchers have distributed Line Evaluation Trials (LETs) on a limited scale to several different countries to obtain information on general performance of maize inbred lines in different locations. For some subprograms, it has now become standard practice to distribute such trials to identify superior high yielding stable inbreds to guide on-going hybrid related activities. Means for grain yield and other characters of yellow and white maize inbreds from a few source populations are listed in Table 1. Yield differences among lines derived from different source populations are evident. Yield levels ranged from 2.44 tons/ha in pool 24 to 4.05 tons/ha in inbreds population 36. In each group a few inbreds from different source populations performed exceedingly well for yield and were also stable in performance across locations (data not shown). In recent trials conducted with tropically adapted lines, some inbreds from populations 43, 21, 32, 27, 24 and pool 24 have yielded almost 6 tons/ha (personal communication H. Cordova).

Line evaluation trials under abiotic stresses

These trials have been conducted for several different stresses including drought tolerance, low nitrogen (Low N tolerance), and even for acid soil tolerance. Huge amount of data has been accumulated and some published in the proceedings of various regional workshops and in the proceedings of drought and low N symposium held at CIMMYT headquarter El Batan, Mexico from March 25-29, 1996 (VASAL *et al.*, 1997). Only four sets of data from different groups of tropically adapted maize inbreds were chosen to illustrate behavior for yield and other traits that contribute to drought tolerance (Table 2). Information on general performance of inbreds under drought stress was obtained mostly at CIMMYT station at Tlaltizapan in Mexico. Some of the lines collapsed completely or yielded practically very little under drought stress (Table 2). On the other hand some of the lines yielded well compared with the

TABLE 1 - *Means for grain yield and other characters of inbreds developed from different source populations.*

Material	No. of inbreds	Grain yield (t/ha)	50% silking (days)	Plant height (cms)	Moisture (%)
Population 21	24	2.54	63	161	28.2
Population 43	43	2.68	62	169	27.2
Pool 24	4	2.44	64	142	30.5
Tux. Sequia	3	3.11	62	165	28.3
Population 24	12	3.30	60	157	23.0
Population 27	5	3.80	62	171	23.8
Population 36	5	4.05	59	175	21.6
Population 28 TSR	8	3.05	63	158	22.3
Sint. Amar. TSR	30	3.37	61	162	24.0

TABLE 2 - *Information on grain yield in inbred evaluation trials under drought stress.*

Trial name	No. of entries	Range (kg/ha)	Mean of top 10 entries (kg/ha)	Mean kg/ha
LETW-9501	196	0-4844	4224	1953
LETY-9502	121	194-5045	4351	2291
Late lines across SS+IS and H+ND	50	0-789	604	277
Early lines under IS+HD	49	10-2352	1511	743

TABLE 3 - *Evaluation of tropical late white inbreds under drought stress-LETW-9501 Tlaltizapan, 1995A.*

Pedigree	Yield (t/ha)	Anthesis silking interval	Ear aspect†
POB.21C5HC219-3-1-B-======-B-=	4.8	0.7	1.8
TUXP.SEQUIA.21-1-2-1-B-==-2-BB-f-==-B	4.6	0.9	2.0
SINT.BCO.TSR-3-1-2-3-2-BBBB-==-B-B-B-=	4.3	0.2	1.8
POB.49STE-C2-8-BBBB-=-B-=	4.1	0.2	1.8
POB.25(STE)C2-51-BBBB-==-B-=	4.1	0.1	2.3
(21F219*43F95)-5-BBB-1-==-B-=	4.0	1.7	3.3
SINT.BCO.TSR-7-3-1-2-3-BB-f-==-=	3.8	2.0	2.3
(21F114*21F38)-5-3-2-1-BB-f-==-B	3.8	2.0	3.0
POB.21(MRRS)C1-926-2-BBBBB—B-=	3.6	0.1	1.8
POB.21(MRRS)C1-321-1-BBBB-==-B-=	3.5	0.4	2.5
POB.43C6HC133-1-5-1-B-B-B-===-B-=	3.4	0.3	3.0
(TSEQUIA49*FERKE8243-58)-BBBBBBB-=	3.3	0.9	2.5
(POB43F95*21F219)-1-BBB-1-=*4-B-=	3.3	2.0	3.3
POB21C6S1MH247-5-B-1-1-2-BBB-1-====—B-=	3.3	1.3	2.3
POB.49STE-C2-26-BBBB-=-B-=	3.3	0.1	2.3

† Ratings : 1-Excellent; 5-poor.

mean of the trial. Inbred yields of evaluation trials subjected to combined drought and high plant density stressed were severely affected with trial mean of only 277 kgs/ha. Even under such combined stresses, some inbreds yielded reasonably well. The top 10 inbreds in this trial yielded 604 kgs/ha. Earlier maturity inbreds tested in another trial under drought and high plant density stresses performed better than the later inbred lines. The average yield of inbreds in the trial was 743 kgs/ha with some top performing ones yielding as much as 2352 kgs/ha.

The actual yield performance of late white and yellow inbreds are given in Tables 3 and 4. Under intermediate drought stress, some of the lines yielded more than 4 tons/ha. The anthesis silking interval (ASI), which is considered as an important trait contributing to drought, was not affected. Some of the lines registered no effect of drought stress whereas in others it was prolonged by 2 days. The quality of ears as judged by ear aspect was good in top performing lines. Most of the top performing lines in these two trials rated between 1.0 and 3.3 on a rating scale of 1 to 5; 1 being more desirable and 5 extremely undesirable. The results from these studies have strengthened belief of CIMMYT researchers that useful drought tolerant lines can be identified through indirect strategies by evaluat-

TABLE 4 - *Evaluation of tropical late yellow inbreds under drought stress-LETY-9502. Tlaltizapan, 1995A.*

Pedigree	Yield (t/ha)	Anthesis silking interval	Ear aspect†
CML20	5.0	0.3	1.5
CML52	4.8	1.6	2.0
(-22F128*P22F25)-2-2-2-2-BB-f-==-B	4.7	0.1	1.5
SINT.AM.TSR-93-2-2-2-2-BB-f-==-B	4.4	1.7	1.8
CML27	4.4	2.2	2.3
(POB24STE-16*24STE-17)-BBBB-===-B-=	4.3	0.1	1.0
POB.36C5HC144-2-2-B-=*10-13-B-=	4.3	0.2	2.3
CML29	3.9	0.3	2.3
CML40	3.8	0.4	2.8
CML31	3.8	0.6	2.0
POB.24(STE)C2-29-B-B-B-B-B-B-B-=	3.6	1.3	1.5
POB.24C5HC227-1-2-1-2-B-6-1-====-BB-====-B-=	3.5	1.8	1.5
POB.28TSR-3-1-1-4-B-===-BB-====-BB-=	3.3	1.9	2.0
S.AM.TSR-4-1-1-1-1-BB-f-==-=	3.3	0.4	1.8
POB.24STEC2-35-BBBBB-B-=	3.3	2.1	1.5

† Ratings : 1-Excellent; 5-poor.

TABLE 5 - *Top performing tropical CML's evaluated under low-N at Poza Rica, Mexico 1995-B.*

CML NO.	Yield (t/ha)	ASI† (days)	Ear/plant height‡	Ears per plant	Ear rot§
273	4.41	−0.5	0.43	1.1	2.5
294	4.11	−1.0	0.50	1.3	1.6
31	3.91	−2.0	0.44	0.9	1.4
20	3.87	0.0	0.44	1.0	1.4
18	3.84	0.0	0.54	1.0	1.1
271	3.71	−1.0	0.46	1.0	1.8
8	3.59	−1.5	0.46	1.0	2.2
298	3.56	0.0	0.41	1.0	1.8
258	3.38	−3.0	0.42	1.1	2.4
27	3.35	0.5	0.38	1.1	2.1
5	3.31	−3.0	0.49	1.0	1.5
259	3.26	0.5	0.40	1.1	2.8
Overall mean	2.53	0.4		1.0	2.2

† ASI = Anthesis silking interval in days.
‡ Ear to plant height ratio.
§ Rating : 1-excellent; 5-poor.

ing potentially useful and agronomically desirable inbreds under artificial drought stress conditions. The value of drought stress research can be enhanced by developing inbreds under higher plant densities during inbreeding which seems to be efficient and effective indirect tool for developing drought tolerant inbreds.

Limited data have been generated by evaluating lines under low nitrogen stress. Several CMLs were evaluated by CIMMYT stress physiologists under zero nitrogen. The performance for yield and other traits for some of the better performing inbreds is given in Table 5. Some of the top performing inbreds yielded as much as 4.0 tons/ha and more. The ASI was not affected. Two CMLs 258 and 5 had negative ASI of 3 days which is considered desirable. Low N tolerant lines were also identified in some highland populations 902 and 903. Superior tolerant fraction was identified and recombined to develop a N-use efficient synthetic. The stress physiologists have pursued this work very vigorously at CIMMYT and some low N tolerant populations have been developed and methodology well established.

Released CMLs have also been evaluated in Cali, Colombia for tolerance to soil acidity. CMLs 27, 36, 40, and a few lines developed from tar spot resistant synthetics were identified as resistant lines. The highland maize inbreds have been evaluated for cold tolerance. Several lines possessing higher level of tolerance to low temperatures were identified. Some of the top performing inbreds were HTBA 136-58, HTBA 125-57, CML 239, and CML 242.

Inbred line evaluation nurseries for biotic stresses

Losses occurring due to diseases and insects are major constraints to increased maize production. A range of diseases and insects are reported in maize which damage the crop at different stages of crop growth and some even affect maize ears and grains. The volume of data available at CIMMYT for biotic stresses is too large and these cannot be included in this paper. An attempt, however, has been made to include important information in a concise and meaningful fashion. The number of diseases and insects that need to be studied are varied in nature and the list is too big. The complexity of inheritance and the reliability of natural and artificial screening procedures for some of the problems make the task of the breeders more difficult. The population improvement approaches have been suggested and used successfully but the progress is generally slow for polygenically inherited traits as compromises are made during selection for several traits simultaneously. CIMMYT maize researchers have used problem solving strategies recently that rely heavily on inbred-hybrid approach. Evaluation and screening of maize inbreds, especially where the techniques are not completely reliable and the frequency of resistant genotypes is low, have proven successful in detecting tolerant or resistant lines from diverse maize populations. The results of several studies will be presented without including all the details.

TABLE 6 - *Promising advanced white inbreds screened and identified as resistant to fall armyworm* (Spodoptera frugiperda) *and sugarcane borer* (Diatraea saccharalis) *during 1995B.*

Pedigree	Fall armyworm		Sugarcane borer	
	Mean rating†	Mean ear aspect‡	Mean rating†	Mean ear aspect‡
POB21C6S1MH134-1-B-1-3-1-BBB-2-##-BBB-=	4.5	3.0*	4.5	3.5
POB21C5HC84-F3-#-5-B*7-=	4.4	2.8*	4.9	2.8
POB21C6S1MH177-2-B-4-2-2-BB-f-##-#	4.5	3.0	4.0	2.3
CML262 POB21C6S1MH177-2-B-4-3-1-BB-f-##-#	4.5	3.0	5.0	2.8
POB21C6S1MH247-5-B-1-1-2-BBB-4-####-B-=	4.4	3.0	4.3	2.5
POB21C5HC218-2-3-B-==-6-2-1-BBBB-1-====-B-=	4.1	3.0	4.3	3.0
POB21C5HC218-2-3-B-==-6-2-1-BBBB-4-====-B-=	3.6	2.8	4.6	2.3
FFRKE8243-51-1-1-B-==-3-BBB-1-==-BBB-=	4.1	3.0	5.0	3.0
CML257 POB21C6S1MH154-5-B-1-1-1-BB-f-##-B-B	4.4	2.8	5.0	2.8
CML262 POB21C6S1MH254-2-B-1-4-4-BB-f-==-B-B	4.2	3.3	5.0	2.5
CML67 RESISTANT CHECK	4.0	3.5	4.1	3.5
CML131 SUCEPTIBLE CHECK	6.4	3.5	6.8	3.5

† Rating : 1-highly resistant; 5-highly susceptible.
‡ Rating : 1-excellent; 5-poor.

Screening of Maize Inbred Lines for Insects

Several CIMMYT released inbreds and some promising lines have been screened for two important insects, namely fall armyworm (*Spodoptera frugiperda, Faw*) and sugarcane borer (*Diatraea saccharalis, SCB*) under artificial infestation. The lines selected for such evaluations were agronomically good and were highly inbred past S6 or S7 inbreeding generation. Also, relatively high plant population densities were used in these trials. The results of insect evaluation trials were interesting where 10 common white lines were found to be tolerant to FAW and SCW (Table 6). The inbred line evaluation trials in 1996 also measured grain yield and insect damage ratings under artificial infestation to both insects (Table 7 and 8). Several top performing CMLs under artificial infestations to FAW and SCW yielded exceedingly well ranging from 3.5 to 6.5 tons/ha. The grain yield of these inbreds were well above the resistant checks used in these studies. The insect ratings ranged from 3.5 to 5.0 on a rating scale of 1 to 9 (1-resistant, 9-susceptible). These ratings were lower than the susceptible check but higher than the resistant check which had a rating 2.8 for FAW and 2.4 for SCB. Most of the lines had good ear aspect as reflected by lower ratings than both the susceptible and resistant checks.

The studies identified sources of resistance to both the insects in agronomically superior performing inbreds for yield and other traits.

Inbred Line Evaluation Nurseries for Diseases

CIMMYT maize inbreds have been screened to perfect inoculation techniques and to identify sources of resistance for an array of problems which are frequently present in the lowland tropics such as downy mildew, maize streak virus (MSV), stunt virus, banded leaf and sheath blight, rust, and several ear rot causing organisms such as *Fusarium moniliforme* and diplodia ear rot (*Stenocarpella maydis*). Through inbred evaluation nurseries several sources of resistance have been identified and have been made available to the national programs for their use in forming resistant/tolerant hybrid maize combinations and developing resistant open-pollinated varieties (OPVs) and synthetics.

The evaluation of CMLs, and other promising CIMMYT maize inbreds to different diseases has given interesting and encouraging results. It is important to emphasize that none of these lines had been previously screened for any of the diseases described earlier. Specific tolerances/resistances identified for each of the above diseases is discussed in the following text.

Among 120 CMLs evaluated for maize streak virus (MSV) under artificial conditions by CIMMYT maize researcher in central and western Africa, at least six maize inbreds were found to be resistant or moderately resistant with ratings of 2.0 and below on a rating scale of 1 to 5. The inbreds found resistant were CMLs 256, 270, 273, 277, 278, and 281 among the white

TABLE 7 - *Evaluation of tropical yellow lines to fall armyworm* (Spodoptera frugiperda) *under artificial infestation during 1996A.*

Pidigree	Ratings† (1-9)	Yield (t/ha)	Ear aspect‡ (1-5)
POB24STEC1HC17-1-2-1-1-1-BBB-1-===-B-B-B	4.1	6.52	3.2
POB24STEC1HC17-1-2-1-1-1-BBB-1-=*4-B-B-B-B	4.4	5.90	2.7
CML295SINT.AM.TSR-76-2-1-1-1-BB-f-==-=-B	4.3	5.63	2.7**
CML294SINT.AM.TSR-93-2-2-2-2-BB-f-==-=-B	4.8	5.23	2.3*
S.AM.TSR-76-1-2-3-1-BBBB-==-B-B-B-B-B-	4.7	5.15	2.0***
POB.287SR(S2)-3-1-2-2-B-===-B-2-B-B	3.5	5.04	2.5*
(POB24STE-5*24STE-17)-BBBB-===-B-B-B-B	3.6	4.97	2.5*
SINT.AM.TSR-23-2-2-1-2-BBBB-==-BBB-=-B-B	4.5	4841	2.7
POB24C5HC227-1-2-1-2-B-6-1-====-BB-====-B-B-B	4.3	4.82	3.0
CML300SINT.AM.TSR-76-1-2-3-1-BB-f-==-=-B	4.4	4.71	2.2***
POB36C9HC135-B-5-B-B-B-B-B	4.1	4.64	3.4
POB28TSR(S2)-3-1-1-3-1-===-B-4-B-B	3.5	4.62	2.9**
(POB.24XPOB.24)-1-2-2-3-BBB-4-B-=-BBB-=-B-B	4.6	4601	2.0***
CML302SINT.AM.TSR-7-1-2-B-1-1-BB-f-==-=-B	4.8	4.56	3.0
POB27C5HC71-3-1-B-====-=-=-B-B-B	4.8	4.29	2.7*
CML-67 (Resistant check)	2.8	5.70	3.7
CML-131 (Susceptible check)	5.6	1.37	3.2

† Rating : 1-highly resistant; 9-highly susceptible.
‡ Rating : 1-excellent; 5-poor.

group of lines (Table 9). Similarly for downy mildew, nine inbreds were found to be moderately tolerant. The percentage of plants affected by downy mildew ranged from zero to 39.21% (Table 10). Inbred CML 50 was found exceptionally resistant with no symptoms of downy mildew occurrence. The tolerance or resistance to banded leaf and sheath blight had been lacking. A few inbreds were found to be moderately tolerant and had disease rating of 3.0. The inbreds were CML 9, CML 19, CML 55, CML 254 and CML 305.

In regards to stunt, a large number of inbreds has been evaluated under artificial conditions. At least 46 inbreds were found to be tolerant/resistant. Seven inbreds, however, seemed to be desirable possessing good levels of resistance to stunt virus (Table 9). Among seven more resistant inbreds, five were CMLs

TABLE 8 - *Evaluation of tropical yellow inbreds for sugarcane borer* (Diatraea saccharalis) *under artificial infestation during 1996A.*

Pidigree	Ratings† (1-9)	Yield (t/ha)	Ear aspect‡ (1-5)
SAM.TSR-76-1-2-3-1-BBBB-==-B-B-B-B-B	4.6	5.43	1.5****
CML20POB24C5HC34-2-3-B-ff-==-=-B	5	5.26	2.3***
POB.28TSR(S2)-3-1-2-2-B-===-B-5-B-B	4.8	4.24	2.5*
CML300SINT.AM.TSR-76-1-2-3-1-BB-f-==-=-B	4	4.22	1.8***
(24STE-5*24STE-17)-BBBB-===-B-2-B-B	4.8	4.19	2.3**
POB.28C9HC113-3-1-4-B-B-B-B	4.7	4.03	2.3*
POB27C5HC71-3-1-B-====-=-=-B-B-B	4.7	4.30	2.3*
SINT.AM.TSR-23-3-2-4-1-BBBB-====-B-=-B-B	4.8	4.03	2.0**
SIN.AM.TSR-23-2-2-1-2-BBB-B-===-5-B-B-B-B	4.8	3.89	2.5
CML287(24f26*27f1)-4-1-B-1-1-BB-f-==-=-B	5	3.86	1.8***
P28TSRS2-3-1-1-3-1-===-B-B	5	3.85	2.3*
P-3SINT.AM.TSR-76-2-1-1-BB-=*5-=-B-B-B	4.6	3.82	2.5
(24f26*24f34)-1-2-2-3-BBB-3-B-=-BBB-B-B	4.8	3.68	2.0**
(POB.24XPOB.24)1-2-2-3-BBB-4-B-=-BBB-=-B-B	4.5	3.67	2.0*
(POB.24XPOB.27)-4-1-B-1-1-BBB-2-B-==-BB-=-B-B	4.5	3.50	2.5
CML-67(Resistant check)	2.4	0.35	3.3
CML-131 (Susceptible check)	5.3	0.27	3.3

† Rating : 1-highly resistant; 9-highly susceptible.
‡ Rating : 1-excellent; 5-poor.

TABLE 9 - *Summary results of inbred line evaluation nurseries.*

Stress type	No. of inbreds evaluated	No. tolerant/ resistant	Remarks
Maize streak virus (MSV)	120	6	CMLs 256, 270, 273, 277, 278, 281
Downy mildew	120	9	CMLs 50, 32, 307, 286, 47, 22, 287, 269, 52
Banded leaf and sheath-blight	120	5	CMLs 9, 19, 55, 254, 305
Acid soils	120	5	CMLs 27, 36, 40 Sat. 76-1-2-2-2-BB-f Sat. 46-1-1-1-2-B-B
Fusarium moniliforme			
White	121	17	Rating > 1.5
Yellow	121	21	Rating > 1.5
Stunt virus			
white	121	5	Below 10% infected plants
yellow	121	5	Below 10% infected plants
Rust (Puccinia polysora) White lines	–	15	POB21C5HC72-3-1-2-B*4-##-1-BBB POB21C5HC84-F3-#-2-B*8 POB21C6S1MH177-2-B-4-3-1-BB-f-##-B POB21C5HC218-2-3-B-###-B-1-#*5-BB POB22TSR(S2)-5-1-1-1-3-###-BB POB23(STE)C2-6-B-B-B-B-B-BB POB25STEC1HC2-1-1-1-1-2-BBB-1-##-B*4 POB32(MRRS)C1-66-1-B*8 LAPOSTA SEQUIA-COS3-12-1-1-B*8 (POB43STE-15*43STE-25)-B*4-###-BB POOL24C20MH94-1-4-B-2-#-BB-1-B-BB POOL24C20MH6-1-2-B-3-3-###-BB POOL24(S1)-2-B-4-B-###-BB (P24TSR19*21F199)-1-1-B-2-2-B*3-1-B-#B*4 (P24F119*P24F54)-6-3-2-1-BBB-1-B-#-B*3
Rust (Puccinia polysora) Yellow lines	–	14	POB27(STE)-C2-36-B*5 POB28F107-1-1-3-2-#-B*5 POB28TSR(S2)-3-1-1-4-B-###-BB POB28TSR(S2)-3-1-1-3—1-###-BB-f-BB POOL26C19MH17-3-2-BBB-####-BB SINT.AM.TSR-7-4-2-2-1-B*4-##-B*5 SINT.AM.TSR-23-2-2-1-2-B*4-##-B*4 SINT.AM.TSR-23-3-1-2-4-B*4-##-B*4 SINT.AM.TSR-76-1-2-3-1-B*4-##-B*4 SINT.AM.TSR-23-3-2-3-2-BB-f-##-B SINT.AM.TSR-23-2-2-1-2-B*4-#*4-BB SINT.AM.TSR-23-3-2-3-5-B*4-#*4-BB SINT.AM.TSR-76-1-2-3-1-B*4-#*4-BB SINT.AM.TSR-23-2-2-1-2-B*4-###-BB
Tar spot (Phyllachora maydis) White Lines	–	9	P22TSR.C3-39-2-B-3-B-B (P43STE-10*43STE-19)-B*4-#-BB-3-BB FERKE8243-51-1-1-B-##-1-B*3-1-##-B*3-4-BB (P21TSR*21F219)-4-BBB-4-###-B-1-BB G24C20MH119-2-1R-#-1-B-B G24C20MH154-4-1-#-1-B-B P22TSR.C4-158-2-5-B-B-B SINT.BCO.TSR.C4-4-1-B-2-B P21C6S1MH226-F3-#-10-B*7-B
Tar spot (Phyllachora maydis) Yellow Lines	–	5	(P26*28)-3-1-1-2-BBB-4-B-#-BBB-2-BB P28TSR(S2)-3-1-1-3-1-###-B-3-B-B P28TSR(S2)-3-1-2-2-B-###-B-1-B-B (P24STE-5*24STE-17)-B*4-###-B-2-BB P28TSR(S2)-3-1-1-3-1-###-2-B-B

TABLE 10 - *Reaction of CML inbreds to downy mildew infection (%).*

Inbred	Plants infected† (%)
CML 50	0.00
CML 32	11.10
CML 307	17.30
CML 286	31.35
CML 47	31.95
CML 22	33.55
CML 287	35.00
CML 269	35.25
CML 52	39.20

† Evaluated at Farm Suwan, Thailand.

TABLE 11 - *Reaction of CML inbreds to Fusarium moniliforme ear rot.*

Inbred no.	Infection (%)
CML-256	1.0
CML-272	1.0
CML-304	2.4
CML-297	2.6
CML-276	3.2
CML-275	3.5
CML-282	4.0
CML-307	4.1
CML-296	4.7
CML-298	5.8
CML-295	6.0
CML-300	6.8
CML-249	6.9
CML-279	7.1
CML-302	7.5
CML-299	7.6
CML-248	7.7
CML-274	7.7
CML-265	9.0
CML-292	10.5
CML-3.8	11.3
CML-267	11.4
CML-255	11.8
CML-266	11.8

TABLE 12 - Inbreds resistant to diplodia ear rot (*Stenocarpella maydis*).

Inbred	Ear infection %
CML-268	0.0
CML-298	1.6
CML-270	10.0
CML-307	10.0
CML-253	12.8
CML-300	13.8
CML-288	16.7
CML-269	17.5
CML-295	18.1
CML-264	20.4

(16, 42, 247, 268 and 273) and two others from population 24 and population 28 selected for inbreeding tolerance and downy mildew resistance. For rust (*Puccinia polysora)*, no satisfactory inoculation techniques are yet available. Therefore, the inbreds were evaluated under natural conditions at Poza rica during the summer cycle when the disease incidence is quite severe. From various types of inbred line evaluation nurseries for yield as well as agronomic traits, several inbreds have been detected which carry good levels of resistance to rust. Fifteen white inbreds resistant to rust have been identified from populations 21, 22, 23, 25, 32, 43 and 24. Similarily, another 14 yellow lines have been found resistant to rust from populations 27, 28, 26, and Sintetico Amarillo TSR. As is evident that the tar spot resistant synthetic possesses a higher frequency of lines resistant to rust (Table 9). Another important maize disease, the tar spot complex, has been prevalent in Mexico for a long time. Satisfactory resistance to this disease had been difficult to find as the occurrence of this disease is complicated due to the presence of another disease organism known as *Monographella maydis* in addition to *Phyllacora maydis*. CIMMYT maize program efforts in accumulating resistance to both these pathogens has been quite slow and at times quite frustrating. However, with massive inbreeding efforts underway at CIMMYT, Mexico, a number of inbreds has been found completely resistant to these problems. The lowland tropical maize program has identified nine white lines and five yellow inbreds that are almost inmune to *Phyllacora* and *Monographella maydis* (Table 9). In the yellow lines, three of the five lines appear to be sister lines. The white lines represented different sources such as populations 21, 22, 43, white tar spot resistant synthetic, and pool 24. Most of the yellow lines were derived from population 28 and two of them were recycled second generation lines. The identification of resistant lines has greatly facilitated development of tar spot resistant populations. Ear rot causing pathogens are widely distributed around the world. The disease incidence is quite severe in hot humid environments. A large number of inbreds have been evaluated for two major ear rots (*Fusarium moniliforme* and *Stenocarpella maydis)*. Some of the better performing lines alongwith percent infection are given in Tables 11 and 12. For *Fusarium moniliforme*, 121 white and 121 yellow lines were evaluated (Table 11). Several CMLs had low infection with 19 lines exhibiting infection less than 10%. For ear rot percentages for *Diplodia*, at least four CMLs 268, 298, 270 and 307 had percent ear rot infection 10% and lower (Table 12).

From the foregoing discussion and data presented, it seems that by and large indirect strategies have helped identify several sources of tolerant/resistance to major insects, diseases, and some abiotic stresses. The success varied for each problem but without exception some resistant sources were detected for pratically every problem. In general for most diseases, insects and abiotic stresses such as drought and low N, enough lines were found tolerant/resistant to accelerate development of stress tolerant OPVs and hybrids.

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