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HETEROTIC PATTERNS OF EIGHTY-EIGHT WHITE SUBTROPICAL CIMMYT MAIZE LINES

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ABSTRACT - Hybrid-oriented source germplasm with established heterotic pattern is essential for initiating hybrid development. The objective of this study is to identify and form heterotic groups of maize (*Zea mays* L.) with subtropical adaptation. Eighty-eight inbred maize lines derived from six CIMMYT subtropical maize populations and pools were crossed to four tester lines, one each from Pool 32 and Populations 34, 42 and 44. The 352 line x tester hybrid combinations were divided into four sets, each set comprising of crosses of 22 lines with the four testers, and evaluated during two seasons at Tlaltizapan, Mexico during 1989 and 1990. Mean grain yields for the four sets ranged from 9.0 t/ha (set 1) to 8.2 t/ha (set 4). General combining ability (GCA) and specific combining ability (SCA) for grain yield were calculated by line x tester analysis. Of the 88 lines tested, 14 from Population 44, 11 from Population 42, nine from Pool 32 and one from Population 34 had positive GCA effects for grain yield. Among testers, Tester 2 (Pop. 44) showed positive GCA effects for yield, and Tester 1 (Pool 32) had negative GCA effects for yield. Significant differences were observed for SCA effects for yield in the different line x tester crosses. Several combinations were identified having yields of 10 t/ha or more and possessing high SCA effects. Interpopulation crosses generally outyielded and had greater SCA effects as compared with intrapopulation crosses. Superior intrapopulation combinations, however, were observed among crosses involving lines from Population 44. Two heterotic groups STHG "A" and STHG "B" are being formed from these materials using the testcross data. Several of the lines included in this study were announced as CIMMYT maize lines (CML) during 1991 and are made available to our cooperators worldwide. Twelve of the 20 top-yielding single crosses (five from each set) were between CML lines. The material and information generated from this study may be useful for future hybrid development work at CIMMYT and in other public and private breeding programs, particularly in the developing world.

KEY WORDS: *Zea mays* L.; Heterotic patterns; Subtropical germplasm; Combining ability.

INTRODUCTION

Maize is grown on more than 17 million hectares under subtropical environments around the world (CIMMYT, 1988). Mean yields of maize grown in such environments, however, are less than 2 t/ha (CIMMYT, 1990). Large-scale adoption of high-yielding hybrids is not common among maize growers in the subtropics except in a few countries like India, Argentina, Egypt and Zimbabwe. Lack of superior source germplasm suited for hybrid development, as well as seed production constraints, are considered to be major contributing factors to this slow progress in adoption of hybrids in the developing world (Vasal and Srinivasan, 1991). Some of the well-known heterotic patterns among tropical and temperate maize germplasm were documented by Goodman (1978). Even in temperate maize breeding programs where considerable yield gains have been realized, the heterotic patterns exploited are limited and need to be diversified (Duvick, 1984). Hybrid maize program at CIMMYT, started in 1985, has obtained information on the heterosis and combining ability of CIMMYT's subtropical maize populations and pools (Vasal *et al.*, 1987; Beck *et al.*, 1991; Vasal *et al.*, 1992a; 1992b). It was considered necessary, however, to explore opportunities for identifying new heterotic groups in addition to exploiting existing ones.

Although maize breeders wish to obtain new genetic diversity that could be exploited, very few organizations have the expertise or resources for this type of work (Duvick, 1985). CIMMYT, because of its commitment and mandate to provide its clients in the developing world with new and superior germplasm, took up the task of identifying new heterotic groups which could be used in hybrid as well as population improvement programs in national research organizations. Although both inbred and

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TABLE 1 - *Line code and pedigrees of 88 subtropical late white inbred lines and four tester parents included in this study.*

Line code and pedigree Set 1	Line code and pedigree Set 2	Line code and pedigree Set 3	Line code and pedigree Set 4
1 Pop34 FS21 S4-1 (CML 85)	23 Pop34 FS250 S4-2 (CML 90)	45 Pop34 FS21 S4-6	67 Pop34 FS140 S3-1 (CML 87)
2 Pop34 FS21 S4-2	24 Pop34 FS250 S4-3	46 Pop34 FS188 S4-1 (CML 89)	68 Pop34 FS186 S3-1 (CML 88)
3 Pop34 FS21 S4-3	25 Pop34 FS21 S4-4	47 Pop34 FS21 S3-7	69 Pop34 FS21 S4-8
4 Pop34 FS34 S4-1	26 Pop34 FS250 S4-4	48 Pop34 FS57 S3-1	70 Pop34 FS250 S4-6
5 Pop34 FS250 S4-1	27 Pop34 FS21 S4-5	49 Pop34 FS250 S3-5	71 Pop34 FS250 S5-7
6 Pop42 FS90 S4-1	28 Pop42 FS123 S5-1 (CML 92)	50 Pop42 FS236 S4-1	72 Pop42 FS130 S4-1 (CML 94)
7 Pop42 FS128 S4-1	29 Pop42 FS128 S4-2	51 Pop42 FS128 S3-4	73 Pop42 FS140 S4-3
8 Pop42 FS140 S4-1	30 Pop42 FS226 S4-2	52 Pop42 FS159 S3-1	74 Pop42 FS182 S3-1
9 Pop42 FS140 S4-2	31 Pop42 FS128 S4-3 (CML 93)	53 Pop42 FS268 S4-1 (CML 98)	75 Pop42 FS236 S4-2 (CML 97)
10 Pop42 FS226 S4-1 (CML 95)	32 Pop42 FS233 S3-1 (CML 96)	54 Pop42 FS101 S4-1 (CML 91)	76 Pop42 FS226 S4-3
11 Pop44 FS101 S4-1	33 Pop44 FS182 S4-1 (CML 106)	55 Pop44 FS65 S3-2	77 Pop44 FS231 S4-1 (CML 107)
12 Pop44 FS101 S5-2 (CML 104)	34 Pop44 FS195 S4-1	56 Pop44 FS101 S4-4	78 Pop44 FS101 S4-5 (CML 105)
13 Pop44 FS130 S3-1	35 Pop44 FS195 S4-2	57 Pop44 FS182 S3-2	79 Pop44 FS182 S5-3
14 Pop44 FS130 S3-2	36 Pop44 FS65 S4-1 (CML 102)	58 Pop44 FS33 S4-2	80 Pop44 FS195 S5-3
15 Pop44 FS101 S4-3 (CML 103)	37 Pop44 FS22 S4-1 (CML 100)	59 Pop44 FS65 S3-3	81 Pop44 FS195 S5-4
16 P.32 HS32 S4-1	38 P.32 HS256 S5-1	60 P.32 HS142 S4-2	82 P.32 HS233 S4-1 (CML 80)
17 P.32 HS142 S4-1	39 P.32 HS573 S4-1	61 P.32 HS256 S5-2 (CML 81)	83 P.32 HS32 S3-6
18 P.32 HS353 S4-1 (CML 83)	40 P.32 HS573 S4-2	62 P.32 HS41 S3-1 (CML 79)	84 P.32 HS512 S4-1 (CML 84)
19 P.32 HS32 S4-2 (CML 76)	41 P.32 HS32 S4-4	63 P.32 HS256 S4-3 (CML 82)	85 P.32 HS32 S4-7
20 P.32 HS32 S4-3 (CML 78)	42 P.32 HS32 S4-5 (CML 77)	64 P.32 HS353 S3-2	86 P.32 HS256 S5-4
21 P.31 HS436 S5-1	43 P.31 HS436 S5-2	65 P.31 HS266 S3-1	87 P.31 HS436 S5-3
22 Pop47 SWCB S5-1	44 Pop47 Bulk4 S5-1	66 Pop47 Bulk 4 S5-2 (CML 110)	88 Pop47 SWCB S5-2
Testers			
89 T1 P32 C19 HS233 S4 (CML 80)			
90 T2 Pop44 C4 FS65 S4 (CML 101)			
91 T3 Pop42 CA FS128 S4 (CML 93)			
92 T4 Pop34 C5 FS 34 S4 (CML 86)			

* Pedigree is given in a standard format, with Population/Pool numbers followed by family number and level of inbreeding at which the lines were tested. Lines derived from the same family are serially numbered. CML codes for public lines available from CIMMYT are given in parentheses wherever applicable. Abbreviations used: Pop. = Population; P. = Pool; FS = Full-sib; HS = Half-sib; SWCB = Southwestern corn borer tolerant; CML = CIMMYT maize line.

non-inbred progenitors could be used to form new heterotic groups, inbred progenitors will provide better source germplasm suitable for hybrid development. Such new germplasm developed from inbred progenitors will show a higher level of tolerance to inbreeding depression and would result in a higher frequency of superior inbred lines. Hence, it was decided to use only inbred material to form heterotic groups.

The objectives of this study are: 1) to establish the heterotic patterns of 88 superior late white subtropical lines developed by the CIMMYT's hybrid maize program, 2) to identify promising hybrid combinations in the process, and 3) to use the above information to classify the lines into contrasting heterotic groups in order to develop at least two subtropical, late maturing heterotic populations with white endosperm.

MATERIALS AND METHODS

Eighty-eight subtropical white endosperm inbred lines representing S_3-S_5 levels of inbreeding, derived from six CIMMYT's subtropical maize populations and pools, were used for this study. Description of the germplasm used can be found in VASAL *et al.* (1992a, b). To make the trials easily manageable and to facilitate efficient testing and statistical analysis, the materials were divided into four sets, each set including 22 lines crossed to four testers, resulting in 88 hybrid combinations per set. The pedigree and line codes of the inbred lines used in each set are presented in Table 1. Several of these lines were released as CIMMYT maize lines (CML) in mid-1991 and seeds of inbreds supplied to our cooperators on request.

Each set was planted with three replications in a split-plot design with lines as main plots and testers as subplots. The trials were grown in two seasons (referred to as environments hereafter) during the summer of 1989 (July-Nov) and winter of 1989-1990 (Nov-April) at CIMMYT's Maize Experimental Station, Tlaltizapan, Morelos, Mexico (18°N). This research station is located at an altitude of 940 masl and represents the subtropical maize growing environments. Twelve check entries were added to each set for yield comparisons, but were not included for line x tester analysis. The checks were: four superior experimental varieties (EVs) developed at CIMMYT, one each from Populations 34, 42, 44 and 47; Cycle 1 of inbreeding stress tolerant (IST) versions of Population 34, 42, 44 and Pool 32; a superior single cross involving lines from Pool 32 x Population 44; two CIMMYT experimental three-way hybrids, and H-311, a popular local hybrid developed at INIFAP, Mexico. Single-row plots, 5.25 m long, spaced 75 cm apart were planted with 50 cm spacing between hills. The hills were overplanted and later thinned to 2 plants per hill to give an approximate density of 53,000 plants/ha. Data on plant height, days to 50% silk, and root and stalk lodging were recorded before harvest. Fresh ear weight and percentage of grain moisture were measured at harvest. Grain yield (t/ha.) was calculated from plot data, assuming 80% shelling and adjusting the grain moisture to 15%.

Analyses of variance were computed for each environment (E) and combined across environments for grain yield, plant height and days to 50% silk. In the combined analysis, environment effects were treated as random and cross effects as fixed. Combined analyses of the four sets in two environments was done assuming both sets and environments as random effects and the lines and testers as fixed effects.

Line (L) x tester (T) analyses were performed using the method described by KEMPTHORNE (1957). General combining ability (GCA) and specific combining ability (SCA) effects were calculated for grain yield. The statistical model used to obtain the different effects was as follows:

$$Y_{ijk} = u + l_i + t_j + (l \times t)_{ij} + e_{ijk},$$

where,

Y_{ijk} is the kth observation on i x jth progeny, u is the general mean, l_i is the effect of the ith line, t_j is the effect of the jth tester, $(l \times t)_{ij}$ is the interaction effect of the cross between ith line and jth tester, and e_{ijk} is the error term associated with each observation.

A total of 352 line x tester crosses were evaluated which included eight crosses that involved sister lines. These eight crosses showed little or no heterosis. Hence, it would be erroneous to use the yield data from these crosses in calculation of GCA and SCA effects, as they would obscure patterns of combining ability picture of those lines, testers, and their combinations. The method proposed by ECKHARDT (1951), and widely used for calculation of missing single cross data, was adopted with appropriate modification for the line x tester model. The predicted yield values were calculated assuming SCA effects of the missing single cross (in this case sister-line crosses) to be zero. The estimated yield figures are then averaged together with the remaining yields to get a more reliable estimate of the GCA effects.

Using GCA effects for yield, two testers were chosen for differentiating the lines into two heterotic groups. The selected lines were recombined within each group to form the F_1 seeds, which was followed by two more cycles of recombination through bulksibbing. Two new subtropical, late, white, heterotic population were thus formed which will be improved by appropriate recurrent selection schemes to enhance the level of heterosis between them.

RESULTS AND DISCUSSION

Results from analysis of variance for individual sets across the two environments is not shown to conserve space. However, combined analysis across the four sets for grain yield, days to 50% silking and plant height is presented in Table 2.

Grain Yield

Mean grain yield for the trial was highest (9.0 t/ha) in set 1 and lowest in set 4 (8.2 t/ha) with a relatively low CV (7 to 8%) for the four sets. Significant differences for GCA effects were observed among lines in sets 1, 2 and 3 (Data not shown). Combined analyses across the four sets showed significant differences in GCA(L) and GCA(T), SCA (L x T), and their interactions with environments (Table 2).

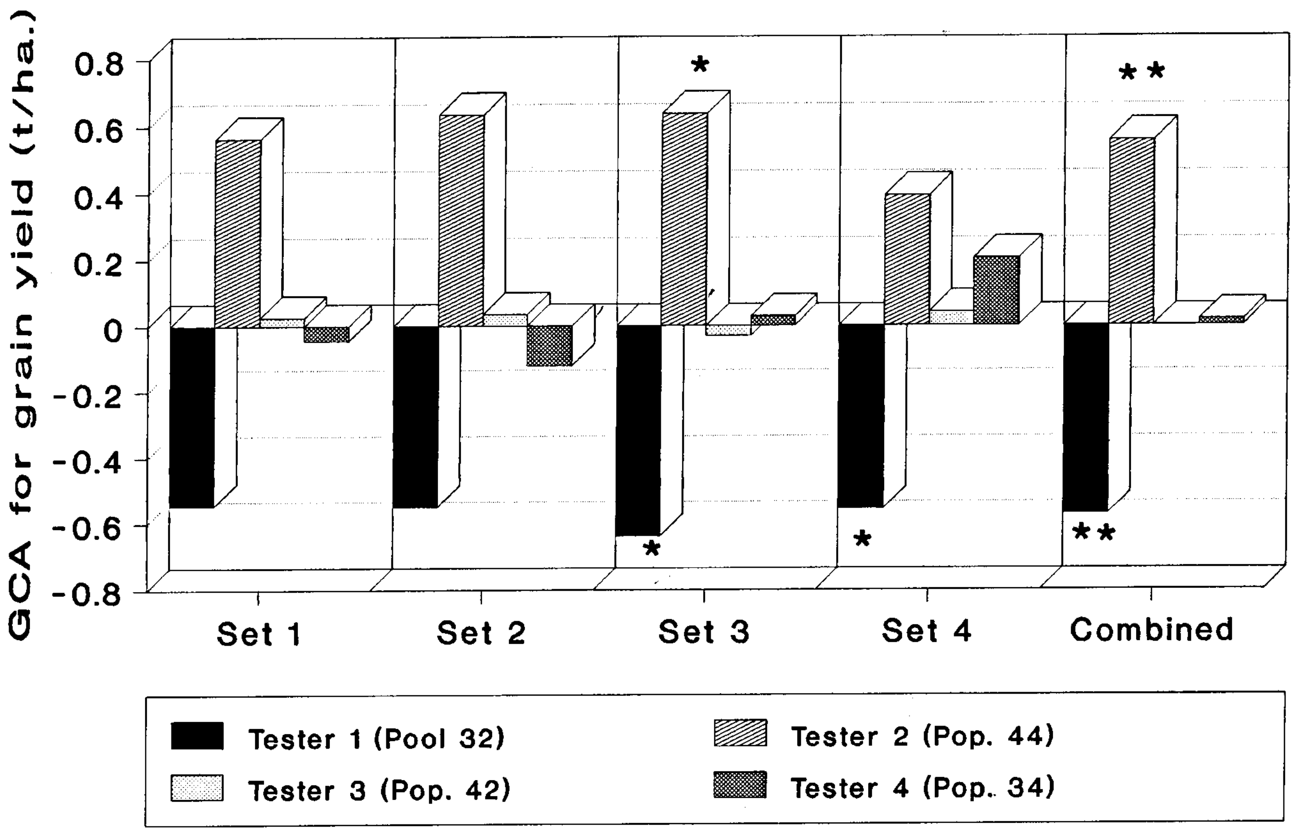
Days to 50% silk

Significant differences were observed for GCA(L) and L x E interaction, whereas GCA(T) effects were not significant due to a high T x E interaction. SCA effects (L x T) were highly significant in the four sets. The interactions of SCA x E was significant only in sets 1 and 2. Mean number of days to 50% silk in the four sets ranged from 74.6 days in set 2 to 73.6 days in set 1. Analyses of variance across the four sets showed significant differences in GCA effects for both lines and testers. Highly significant interactions in L x E, T x E, and L x T x E were observed (Table 2).

TABLE 2 - *Combined analyses of variance across four sets tested in two environments for grain yield, days to 50% silking, and plant height.*

Source	df	Grain yield (t/ha)	Days to 50% silking	Plant height (cm)
Set (S)	3	67.45**	122.16**	9303.71**
S x E	3	39.80**	8.75	3246.98*
S x Rep/(E)	12	2.86	13.42	576.27
Line/(S)	84	6.04**	75.06**	1689.23*
Line/(S) x E	84	1.70**	16.55**	300.93**
Line/(S)* Rep/(E)	336	0.68	2.49	125.74
Tester (T)	3	85.10**	1054.13**	6459.42**
T x E	3	15.50**	187.40**	149.92*
T x S	9	5.25**	7.85**	222.37**
T x S x E	9	1.11**	2.57	49.63
T x Line/(S)	252	7.54**	12.96**	347.34**
T x Line/(S) x E	252	0.80**	2.01**	60.57*
Pooled Error	1056	0.45	1.40	51.33
Mean		8.66	74.14	209.30
CV, %		7.71	1.59	3.42

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.



*, ** denotes significance at 0.05 and 0.01 probability.

FIGURE 1 - GCA effects for grain yield (t/ha.) of the four testers used in this study. GCA values given for each set separately and for sets combined.

Plant height

Highly significant differences were observed for plant height among lines in the four sets individually and combined across sets. Among testers, significant differences were observed in sets 1, 3 and 4. L x T (SCA) effects for plant height was highly significant in each set. While L x E was highly significant in each set, T x E interaction was significant only in set 2 and L x T (SCA) x E interaction was significant only in set 3. Analyses of variance across the four sets yielded similar results (Table 2). Mean plant height for the four sets ranged from 213.6 cm in set 2 to 204.9 cm in set 4 with a CV of 3 to 4%.

Combining ability estimates for grain yield

The means and GCA effects for grain yield for 15 lines that showed significant and positive GCA effects are presented in Table 3. The GCA effects for the four testers are presented for each set and combined across sets (Fig. 1).

Set 1: Highest positive GCA effects were observed with L 15 (0.71 t/ha) followed by L 19 (0.70 t/ha). There were five lines with significantly positive GCA effects (Table 3). Five lines from Population 44 (L 11 to L 15) had positive GCA effects. In constrast, the lines from Population 34 (L 1 to L 5) possessed negative GCA effects except for L 4. Three lines from Pool 32 (L 16, L 19, and L 20) derived from a common half-sib family (HS32) showed significant positive GCA effects for yield. Both lines (L 21, and L 22) from Pool 31 and Pop. 47 had negative GCA effects. Among the four testers, T 2 (Pop. 44), had positive GCA effects whereas T 1 (Pool 32) had negative GCA effects, a trend that was evident in all four sets (Fig. 1).

Set 2: Highest significant positive GCA effects for yield were observed for L 36 (1.30 t/ha.) and L 31 (1.24 t/ha.) (Table 3). Five lines from Population 34 (L 23 to L 27) had negative GCA effects. Three lines each from Population 42 and Population 44 had positive GCA effects. Two lines from Pool 32, which showed significantly positive GCA effects were a derivative of the family HS32. The two lines L 43 and L 44 derived from Pool 31 and Population 47 respectively, were poor general combiners. Among testers, T 2 showed positive GCA effects while T 1 showed negative GCA effects which were not significant (Fig. 1).

Set 3: Greatest GCA effects for yield were exhibited by L 55 (1.15 t/ha.) followed by L 59 (1.00 t/ha.) both derived from Population 44 (Table 3). Eleven lines showed significant GCA effects, with five positive and six negative. Lines from Population 44 (L 55 to L 59) were generally good general combiners, while lines from Population 34 (L 45 to L 49) were poor general combiners. Line 66 (Pop. 47) had a positive GCA effect though not significant (0.31 t/ha.). One line each from Population 42 (L 51) and Pool 32 (L 63) possessed significantly positive GCA effects for yield. Among testers, the same trend was seen as in the other sets, with T 2 having significantly positive and T 1 having significantly negative GCA effects (Fig. 1).

Set 4: Only one line from Population 44 (L 79) showed positive GCA effects for grain yield (0.80 t/ha.) (Table 3). Four lines from Population 34 had negative GCA effects. Three lines from Population 42 (L 72, L 74 and L 75), two from Population 44 (L 78 and L. 79), two from Pool 32 (L 82 and L 83) and one from Pool 31 (L 87) had positive GCA effects for grain yield. The trend among testers was similar to other sets (Fig. 1).

Beck *et al.* (1991) observed that Population 34 x Population 42 crosses had negative SCA effect for yield when tested at Mexican locations, but positive SCA effect when tested at U.S. locations. Similar results were obtained by Oyervides-Garcia *et. al.* (1985) in tests of CIMMYT's subtropical maize germplasm. In our study, however, lines derived from Population 34 had positive SCA effects with tester from Population 42 and vice versa. This suggests that, although heterosis was not exhibited at the population level, improved lines derived from the population could have better cross-performance.

Populations 34, 42 and 44, and Pool 32 had an equal number of lines (20) represented in the four sets combined. Lines derived from Population 34 generally had negative GCA effects, whereas lines from Population 44 had positive GCA effects. Across sets, one line from Population 34, 11 from Population 42, 14 from Population 44 and nine from Pool 32 had positive GCA effects for yield. Only one out of four lines tested from Pool 31 and Population 47 had positive GCA effects.

TABLE 3 - *GCA, and mean grain yield (t/ha) for 15 lines that showed positive and significant GCA effects for yield.*

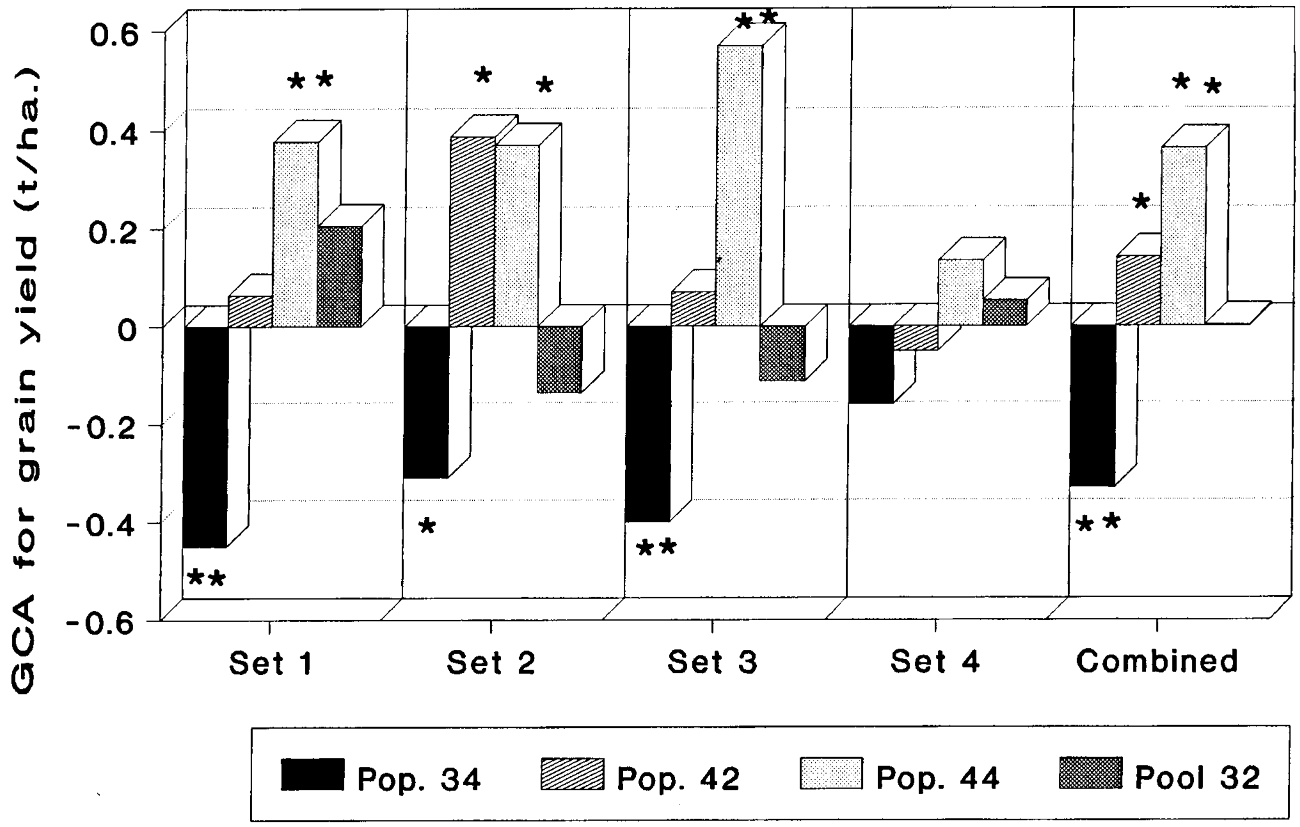
Line number	Yield@	GCA
Set 1		
Line 13	9.7	0.54*
Line 15	9.9	0.71*
Line 16	9.8	0.66*
Line 19	9.9	0.70*
Line 20	9.8	0.65*
Set 2		
Line 31	10.3	1.24**
Line 36	10.4	1.30**
Line 41	9.9	0.79*
Line 42	9.9	0.77*
Set 3		
Line 51	9.8	0.98**
Line 55	9.9	1.15**
Line 57	9.4	0.57**
Line 59	9.8	1.00**
Line 63	9.1	0.36*
Set 4		
Line 79	9.0	0.80**

@ Grain yield (t/ha) of each line averaged over four testers and two environments.

Beck *et al.* (1991) reported the heterosis and combining ability in subtropical and temperate intermediate maturity CIMMYT germplasm and observed that Populations 42 and 47 had positive GCA effects for yield at Mexican locations, but all the pools had negative GCA effects. Results at the inbred line level from our study confirm their findings at the population level with respect to Population 42, where a large number of lines were included. Lines from Population 34 generally had lower GCA effects in our study, whereas Beck *et al.* (1991) observed that Population 34 had positive GCA effects at Mexican locations, and negative GCA effects at U.S. locations. Oyervides-Garcia *et al.* (1985) found that in diallel crosses of CIMMYT experimental varieties, the experimental variety from Population 34 had the second highest average parent heterosis (40.6%).

Intra- vs Interpopulation inter-line combining ability

To compare how the intra- and interpopulation crosses varied in their combining ability, GCA and SCA estimates were determined for the combined performance of the lines within each source population, and within each set (Table 4 and Fig. 2).



*, ** denotes significance at 0.05 and 0.01 probability.

FIGURE 2 - GCA effects for grain yield (t/ha.) of the four source populations (Populations 34, 42, and 44 and Pool 32) from which the lines used in this study were derived. GCA values given for each set separately and for sets combined.

In the four sets and in the combined data, lines from Population 44 consistently had positive GCA effects (Fig. 2). The mean grain yield of lines derived from this population was also higher than the other three populations in the four sets. Lines from Population 42 had significantly positive GCA effects in the second set, but neutral effect in the other three sets. Lines derived from Population 34 exhibited negative GCA effects consistently in the four sets, especially in the first set. Lines from Pool 32 had positive GCA effects in sets 1 and 4 and negative in sets 2 and 3 (Fig. 2).

The SCA effects and the mean yield at the population level using the average of the five lines in each set from each population are presented in Table 4. Intrapopulation crosses are listed diagonally, and the off-diagonals represent interpopulation crosses. One would normally expect less heterosis in crosses involving lines from the same population; this is substantiated by the negative SCA effects seen in all but one of the intrapopulation combinations. The mean yield of the intrapopulation interline crosses (8.3 t/ha.) were also relatively lower than the interpopulation crosses (9.0 t/ha.). However, there were a few intrapopulation crosses which showed good yield potential. For example, crosses between lines from Population 44 in set 1 crossed to T 2 gave a mean yield of 9.7 t/ha which was greater than most of the other interpopulation crosses. Specific high-yielding intrapopulation crosses were identified involving lines from Populations 44 - L 12 x T 2 and L 13 x T 2 (10.4 (t/ha.).

HAN *et al.* (1991) studied differences between intra- and interpopulation crosses involving inbred lines derived from both tropical and subtropical CIMMYT germplasm. They reported an increase in grain yield in the interpopulation crosses of Population 42 x Pool 32 and Population 44 x Population 34 compared to their corresponding intrapopulation crosses by 4% and 7% respectively. In the present study we observed an increase in grain yield of approximately

TABLE 4 - *SCA means and grain yield at the source population level for the 352 line x tester crosses divided into four sets and evaluated in two environments.*

Source Population of lines	Sets	Tester 1 - Pool 32		Tester 2 - Pop. 44		Tester 3 - Pop. 42		Tester 4 - Pop. 34	
		SCA@	Yield (t/ha)	SCA	Yield (t/ha)	SCA	Yield (t/ha)	SCA	Yield (t/ha)
Pool 32	Set 1	−0.32*	8.5	0.03	10.0	−0.01	9.4	0.30*	9.6
	Set 2	−0.39*	8.0	0.17	9.7	−0.05	8.9	0.27	9.1
	Set 3	−0.50**	7.5	0.31*	9.5	0.03	8.6	0.16	8.8
	Set 4	−0.65**	7.0	0.24	8.9	0.11	8.4	0.17	8.7
	Mean	−0.46**	7.7	0.19*	9.5	0.02	8.8	0.22*	9.0
Pop. 44	Set 1	0.43**	9.4	−0.43**	9.7	0.13	9.7	−0.13	9.4
	Set 2	0.34	9.2	−0.56**	9.3	−0.04	9.4	0.14	9.5
	Set 3	0.37*	9.1	−0.71**	8.9	0.08	9.4	−0.02	9.4
	Set 4	0.23	8.1	−0.33*	8.4	−0.02	8.3	0.12	8.7
	Mean	0.34**	9.0	−0.51**	9.1	0.04	9.2	0.03	9.2
Pop. 42	Set 1	0.10	8.8	0.25	10.0	−0.41*	8.8	−0.02	9.2
	Set 2	0.10	9.0	−0.03	10.1	0.08	9.2	−0.11	9.2
	Set 3	0.19	8.4	0.05	9.5	−0.59**	8.0	0.23	9.1
	Set 4	0.20	7.8	−0.15	8.4	−0.17	8.0	0.13	8.5
	Mean	0.15*	8.5	0.03	9.5	−0.27**	8.5	0.06	9.0
Pop. 34	Set 1	−0.09	8.1	−0.01	9.3	0.22	9.0	−0.16	8.3
	Set 2	0.05	8.3	0.06	9.5	0.31	9.1	−0.42*	8.2
	Set 3	0.09	7.8	0.04	9.1	0.20	8.5	−0.32*	8.1
	Set 4	0.14	7.7	0.21	8.7	0.02	8.1	−0.38**	7.9
	Mean	0.05	8.0	0.07	9.1	0.19*	8.7	−0.32**	8.1

@ The SCA values and mean yield are the average of the five lines from each population/pool that were tested in each set.
*, ** Represents significance at 0.05 and 0,01 levels of probability, respectively.

10% in the interpopulation crosses for similar combinations compared to their intrapopulation crosses (Table 4). This suggests that the strategy of breeding for hybrid-oriented germplasm has resulted in a steady improvement in cross-performance of these populations.

The performance of five high-yielding crosses from each set are summarized in Table 5 along with the checks. For comparison purposes, the yields of three best checks are presented. They are: (1) H311, a commercial check from INIFAP, Mexico, (2) CIMMYT EV (TL8244), and (3) CIMMYT single cross hybrid check (Pool 32 x Pop. 44). Data on root and stalk lodging, though recorded, is not included, as there was very little lodging in these materials. Yield superiority of some crosses over the EVs were as high as 40% and 18% over H311 (Table 5). H311, a popular hybrid among the farmers in Mexico, is relatively taller and later compared to the crosses tested here. Grain moisture content at harvest, ranged from 18.3 to 29.7% in the crosses listed (Table 5). Twelve of the 20 high-yielding crosses listed in Table 7 were between released CML lines, which makes this information more valuable for our cooperators who are starting to use these lines in their hybrid programs.

Formation of subtropical maize heterotic groups

The results from this study provided a clearer understanding of the combining ability of the 88 lines tested. Based on the general combining ability of these lines, T 2 and T 4 were used as reference testers and each of the 88 lines examined for their GCA and SCA effects with these two testers. Lines that had positive SCA effects with T 4 and negative SCA effects with T 2 were included under Subtropical Heterotic Group ("STHG A"). Lines that showed negative SCA effects with T 4 and positive SCA effects with T 2 were included under Subtropical Heterotic Group ("STHG B"). Some of the lines that had high positive SCA with both the testers were included in both groups. Lines that showed negative SCA effects with both testers were rejected. Based on

TABLE 5 - *Grain yield, days to silk, plant height, and grain moisture content of five best line x tester crosses from the four sets evaluated in two environments at Tlaltizapan, Mexico.*

Hybrid code[@]	Grain yield (t/ha.)	SCA	% over H 311	% over TL 8244	Days to 50% silk	Plant height (cm)	Grain moisture (%)
Set 1							
L 19 x T 2 (CML76 x CML 101)	10.72	0.29	110.5	134.5	73.0	217	25.3
L 6 x T 2	10.58	0.88	109.1	132.7	74.2	213	22.4
L 9 x T 2	10.56	0.92	108.9	132.5	72.0	209	20.6
L 16 x T 2	10.51	0.13	108.4	131.9	73.0	216	24.4
L 20 x T 4 (CML78 x CML86)	10.38	0.61	107.0	130.2	72.7	224	25.1
Check (H 311)	9.70		–	–	76.5	244	22.5
Best check hybrid[§]	10.05		–	–	72.3	216	22.3
Best OPV (TL 8244)[§§]	7.97		–	–	75.0	209	20.8
Set 2							
L 28 x T 2 (CML92 x CML101)	11.10	0.94	118.3	133.9	75.8	237	22.4
L. 31 x T 4 (CML93 x CML86)	10.64	0.44	113.4	128.3	75.8	219	27.0
L 36 x T 4 (CML102 x CML86)	10.55	0.28	112.4	127.2	73.5	213	29.7
L 33 x T 2 (CML106 x CML101)	10.49	0.31	111.8	126.5	78.5	239	28.4
L 44 x T 2	10.39	0.74	110.8	125.3	73.5	202	23.9
Check (H 311)	9.38		–	–	77.5	240	23.4
Best check hybrid	9.42		–	–	73.3	218	23.8
Best OPV (TL 8244)	8.29		–	–	76.0	210	23.5
Set 3							
L 51 x T 2	10.28	–0.12	107.0	140.6	76.8	218	22.6
L 63 x T 2 (CML82 x CML101)	10.24	0.47	106.6	140.1	72.5	205	21.2
L 61 x T 2 (CML81 x CML101)	10.21	0.84	106.2	139.7	71.8	202	20.2
L 66 x T 2 (CML110 x CML101)	10.09	0.36	105.0	138.0	74.8	217	20.1
L 51 x T 4	10.08	0.29	104.9	137.9	74.5	213	23.3
Check (H 311)	9.61		–	–	75.7	235	22.7
Best check hybrid[§]	8.93		–	–	73.3	216	24.2
Best OPV (TL 8244)	7.31		–	–	75.3	203	21.2
Set 4							
L 83 x T 2	9.69	0.59	104.4	110.5	73.8	202	23.9
L 79 x T 4	9.46	0.22	102.0	107.9	75.7	215	24.1
L 84 x T 3 (CML84 x CML93)	9.38	1.23	101.1	107.0	72.3	219	19.3
L 82 x T 2 (CML80 x CML101)	9.29	0.28	100.1	105.9	72.5	195	20.5
L 84 x T 4 (CML84 x CML86)	9.28	0.88	100.0	105.8	71.3	201	21.4
Check (H 311)	9.28		–	–	77.2	238	23.0
Best check hybrid[§]	8.49		–	–	73.7	214	23.2
Best OPV (TL 8244)	8.77		–	–	74.8	210	18.3

[§] Best CIMMYT's single cross check involving lines from Pool 32 and Population 44.

[§§] Highest yielding experimental variety (EV). TL 8244 stands for EV developed from 10 best full-sib families of Pop. 44 based on evaluation in 1982 at Tlaltizapan, Mexico.

[@] For line and tester codes refer to Table 2. CML stands for CIMMYT Maize line which are announced public lines from CIMMYT. CML code given for applicable crosses.

the contrasting combining ability pattern, 42 lines were included in STHG "A" and 44 lines in STHG "B". Lines from each group were recombined and the resulting F_1 seed was recombined for two cycles through bulk-sibbing. After a few more recombinations, the two heterotic populations will be further improved through appropriate breeding schemes to enhance the level of heterosis between them.

WELLHAUSEN (1988) reported on the heterotic patterns existing between Tuxpeno and the Cuban and Coastal Tropical flints of the Carribean and their utility for the improvement of maize in the lowland tropics. However, there is not much information on the heterotic patterns for subtropical germplasm. This present study to ascertain the heterotic behavior among CIMMYT's subtropical lines and the subsequent formation of new heterotic groups, we believe, would result in providing better and improved maize germplasm for hybrid development work both at CIMMYT, as well as in national programs, in the subtropical regions of the world.

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