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Combining ability among fifteen early cycle maize populations in Brazil

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ABSTRACT

Early maturity maize (*Zea mays* L.) populations are used in short growing season areas, and their use is gradually increasing in tropical areas. The objective of this study was to determine the genetic potential of 15 early maturity maize populations in a diallel crossing system. The 15 parents, 105 diallel crosses among parents, and selfed generation of parents were evaluated in a triple lattice design at 13 locations in Brazil. The combined analyses of variance for grain yield, time to tassel, and plant height indicated highly significant ($P < 0.01$) differences for entries, parents, heterosis, parent heterosis, specific heterosis and for the first-order interactions with environments. Average heterosis was highly significant for grain yield, significant ($P < 0.05$) for time to tassel, and not significant for plant height. Mean yield ranged from 3187 to 5213 kg/ha for populations, and ranged from 3041 to 6017 kg/ha for the population crosses. Population Pool 17 had the largest inbreeding depression effects, whereas population CMS 52 had the smallest inbreeding depression effects. The highest specific cross for grain yield was for Across 8528 x Pool 18. None of the population crosses was superior to the hybrid checks for the three traits. No association was found between endosperm type and heterosis. The results suggest that either the populations themselves or the synthetic composites of selected populations can be used for breeding purposes.

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INTRODUCTION

Late maturing varieties of maize (*Zea mays* L.) are often grown to take advantage of the growing season because late maturity varieties have a greater yield potential (Giesbrecht, 1960). Maize production in some tropical growing areas with later maturing varieties is restricted because of the uncertainty of grain maturity at harvest due to either lack or excess of rainfall before maturity is attained. These conditions are more pronounced for tropical maize areas than for temperate maize areas and, as a result of other environment changes, a greater reduction in yield is observed in tropical maize areas. Use of earlier maturity maize varieties is gradually increasing in tropical regions to reduce the effects of variations in rainfall.

Limited information is available on performance of earlier maturity maize populations in tropical maize areas . The earlier maturity populations usually used in the tropics either include germplasm introduced from temperate areas or are segregating populations from crosses between tropical and temperate germplasm. These populations generally tend to be low yielding and have poor agronomic characteristics.

Early maturity maize varieties are widely used in short growing season areas of temperate regions where later cultivars cannot complete the grain-filling period due to insufficient heat units (Landi *et al*., 1986 and Troyer, 1990). In a study of maize tolerance to heat and drought effects, Troyer (1983) reported that early flowering maize yielded more than late flowering maize in hot, dry seasons due to sub-soil moisture availability during the moisture-critical, stress-susceptible flower-

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ing period. Furthermore, Troyer (1994) reported that early maturity maize materials would be of better use if grown where they can properly mature to obtain maximum yields or where it must grow faster and mature sooner to produce mature kernels in shorter growing seasons.

In some rainfed maize production areas of Brazil, early maturing varieties are essential for successful maize production. The early maturing varieties are necessary if maize is to become an important crop in areas where rainfall is often sporadic, as in the northeast region, and areas where excessive rain frequently occurs, as in the Amazon area. Use of early maturity varieties also could make a better use of land. For those maize growing areas where supplementary irrigation is feasible, three crops per year, or at least five crops in two years, could be produced.

Study of crosses between varieties provides information on the potential of hybrid crosses and heterosis. Thus, varieties can be chosen to be used as parents in the first generation crosses, as base populations in reciprocal recurrent selection schemes, as sources of inbred lines to be used in hybrids, or as sources for synthesis of variety composites (Miranda Filho and Vencovsky, 1984). Diallel analysis has been extensively used by maize breeders to broaden our knowledgment of heterotic patterns and combining ability of populations (Hallauer and Miranda Filho, 1988).

An important objective of the National Center for Maize and Sorghum Research (CNPMS) maize breeding program is the development of earlier maturing and greater yielding maize varieties to meet the needs of specific tropical maize growing areas of Brazil. Hybrid breeding programs in maize require information about the relationship among varieties to make better use of heterosis expressed between varieties. Therefore, the identification of new heterotic patterns and combining ability among these earlier varieties would be useful in hybrid breeding programs. The objective of our research was to evaluate the genetic potential of 15 early cycle maize populations in a diallel crossing system to obtain information for population improvement and hybrid breeding programs.

MATERIAL AND METHODS

The 15 populations included in this study are representative of early cycle tropical maize populations from CNPMS' germplasm bank collection (Table I). Research was initiated in 1989 by CNPMS to increase the potential genetic variability within earlier maturity materials for long-term breeding programs. Most of these populations were obtained by crossing tropical and temperate germplasm. These populations included various proportions of temperate germplasm in tropical germplasm and had undergone selection for adaptation to tropical environments. All of the populations introduced from International Maize and Wheat Improvement Center (CIMMYT) had at least two cycles of mass selection for adaptation to Brazilian environments.

The 15 populations were crossed in a diallel mating system at Sete Lagoas, MG, Brazil, in the 1992 winter season. Two paired rows of 50 plants per row were used to produce each cross where all plants were pollinated to produce 105 possible plant crosses. Seeds from each cross and its reciprocal were bulked to represent each cross. Seed increase of the parents 'per se' and 'self' generation was completed by sibbing and selfing, respectively. Bulk pollen was collected from a random sample of at least 100 plants to produce the seeds for the crosses and for seed increase of the parents. A minimum of 100 selfed plants was also used to obtain the seeds for the selfed parents.

The parents, their selfing generation, their crosses, and nine commercial hybrids checks (144 entries) were evaluated in a 12 x 12 triple lattice design

Table I - Kernel color, endosperm type, and origin of 15 tropical early maturity maize populations evaluated per se, and in crosses.

Population	Kernel color	Endosperm type	Origin[a]
1 - Muneng 8531	Yellow	Dent	CIMMYT
2 - Across 8528	Yellow	Dent	CIMMYT
3 - Pool 17	Yellow	Flint	CIMMYT
4 - Pool 18	Yellow	Dent	CIMMYT
5 - Tropical extra early yellow population	Yellow	Dent	CIMMYT
6 - Pool 16	White	Dent	CIMMYT
7 - Pool 15	White	Flint	CIMMYT
8 - Tropical extra early yellow synthetic	Yellow	Flint	CIMMYT
9 - CMS 51	Yellow	Dent	CNPMS
10 - CMS 37	Yellow	Flint	CNPMS
11 - CMS 55	Yellow	Dent	CNPMS
12 - CMS 56	Yellow	Dent	CNPMS
13 - CMS 52	Yellow	Dent	CNPMS
14 - Composto superprecoce canaforte	Yellow	Flint	CNPMS
15 - CMS 47	Yellow	Dent	CNPMS

[a]CIMMYT = International Maize and Wheat Improvement Center and CNPMS = National Center for Maize and Sorghum Research.

at 13 locations in Brazil during 1993/94. The nine checks included Dina 887, Dina 105, Co 6339, Co 6244, Co 6288, Ag 527, Ag 627, XL 220, and XL 222. The locations of the trials included Sete Lagoas (MG) lat. 19.28 S and long. 44.15 W; Linhares (ES) lat. 19.24 S and long. 40.04 W; Janauba (MG) lat. 15.47 S and long. 43.18 W; Uberlandia 1 and 2 (MG) lat. 18.55 S and long. 48.17 W; Rio Verde (GO) lat. 17.48 S and long. 50.55 W; Itumbiara (GO) lat. 18.25 S and long. 49.12 W; Cravinhos (SP) lat. 21.18 S and long. 47.44 W; Campinas (SP) lat. 22.50 S and long. 47.05 W; Jacarezinho (PR) lat. 23.09 S and long. 51.11 W; Londrina (PR) lat. 23.23 S and long. 51.11 W; Cambe (PR) lat. 23.47 S and long. 51.17 W; and Pelotas (RG) lat. 31.45 S and long. 52.21 W. The experimental unit consisted of one 5 m row spaced 80 cm apart. Plots were overplanted and thinned to one plant per hill with 25 cm spacing between hills to give a final plant density of 62.500 plants/ha. The agronomic management was that recommended for excellent maize production at each experimental location.

Data were collected for several plant and ear traits, but only data for time from planting to tasseling, plant height, and grain yield are presented. Grain yield (kg/ha) was computed assuming 80% shelling and adjusting to 155 g/kg grain moisture. Data on time from planting to tasseling were recorded at nine locations. Data on plant height were recorded at 11 locations, and data on grain yield were recorded at 13 locations.

Statistical analysis

Analysis of variance was conducted for each of the 13 locations and adjusted means were used in the combined analysis of variance across the locations. Locations were considered as random effects and entries as fixed effects in the analysis of variance. The pooled error mean square was used to test the significance of entry by location interaction, whereas entry mean square was tested against entry by location interaction mean square. Main effects were tested against their respective interactions with environment. Gardner and Eberhart's analysis II (1966) was used to partition the total variation among entries for population and heterosis effects. The heterosis effects were further partitioned into average heterosis, parent heterosis, and specific heterosis. Heterosis (%) for grain yield was computed relative to the mid-parent values.

RESULTS AND DISCUSSION

The differences among entries (populations and their F1 crosses) and location x entries for grain yield, time from planting to tasseling, and plant height were highly significant ($P < 0.01$) in the combined analysis of variance across locations (Table II). Similar results were reported by Gama *et al.* (1984), Lopes *et al.* (1985), and Santos *et al.* (1994) for diallel crosses evaluated at different locations. The partition of entries sum of squares showed that parents and heterosis effects were highly significant for the three traits. Parent effects represent part of the additive gene effects and are described as the difference between the mean of a parent per se and the mean of all parents. The heterosis effects are related to the nonadditive gene effects (Gardner, 1967).

Mean squares of parents and total heterosis was consistent for all traits, indicating that the interpopulation dominance effects were of lesser importance than the intrapopulation dominance effects. Gardner and Paterniani (1967) and Parentoni *et al.* (1990) reported similar results for different diallel variety crosses. All of the components of heterosis were highly significant, with specific heterosis (SCA) accounting for the greatest portion of heterosis sums of squares for the three traits.

Heterosis measures the deviation of the observed performance of a specific cross from its expected performance based on population effects, average heterosis, and population heterosis (Crossa *et al.*, 1987). Therefore, there must be at least one interpopulation cross whose high mean value is due not only to population heterosis but also to the interaction between populations (Hallauer, 1972; Miranda Filho and Vencovsky, 1984; Crossa *et al.*, 1990). Average heterosis was highly significant for grain yield, indicating that the yield of the 15 populations in crosses was greater than the average yield of the 15 populations themselves. Average heterosis mean square was significant ($P < 0.05$) for time from planting to tasseling and not significant for plant height. Parent heterosis was highly significant for each trait, indicating the average contribution by a population in its crosses measured as a deviation from average heterosis. Specific heterosis was also a significant component of heterosis, indicating that there were differences among crosses.

General combining ability (GCA) effects were statistically significant (analysis not shown). GCA accounted for 69.3, 73.2, and 71.0% of the total sum of squares among crosses for grain yield, time to tassel, and plant height, respectively. It seems that additive gene effects were more important in the expression of these traits in crosses than nonadditive gene effects, similar to the results reported by Crossa *et al.* (1990), Miranda Filho and Vencovsky (1984), and Gurdian (1994) but different from the results reported by

Table II - Combined analysis of variance of diallel crosses among 15 early maturity maize populations for yield (kg/ha), number of days from planting to tassel, and plant height (cm) evaluated at 13 locations in Brazil in 1993/94.

Source	Mean squares					
	df[a]	Grain yield[b]	df[a]	Time to tassel	df[a]	Plant height
Entry	119	12.34**	119	1[illegible]	119	3290.4**
Parents	14	57.05**	14	87[illegible]*	14	17549.7**
Heterosis	105	6.33**	105	7[illegible]**	105	1398.1**
Average heterosis	1	27.98**	1	44.9*	1	113.5
Parent heterosis	14	16.13**	14	196.1**	14	2946.1**
SCA	90	4.56**	90	54.2**	90	1158.5**
Location (L) x entry	1428	0.86**	952	10.3**	1309	256.4**
L x parent	168	0.89**	112	11.4**	154	217.1**
L x heterosis	1260	0.86**	840	10.1**	1155	261.7**
L x aver. heterosis	12	2.65**	8	14.1**	11	452.2**
L x parent heterosis	168	1.03**	112	13.1**	154	296.0**
L x SCA	1080	0.82**	720	9.6**	990	255.2**
Pooled error	3094	0.69	2142	7.6	2856	215.9
Mean		4620		54		184
CV (%)		17.9		5.1		7.6

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

[a] Data obtained at 13, 9, and 11 environments for grain yield, time to tassel and plant height, respectively.

[b] = x 10^{-6}.

Barandiaran (1993). Highly significant differences were found for the first-order interactions with locations for each trait. On the average, the nine hybrid checks were 29.5% greater yielding, required 10.0% more days to tasseling, and were 3.5% taller than the population crosses (Table III). The coefficient of variation was 17.9% for grain yield, 5.1% for time from planting to tasseling, and 7.6% for plant height in the combined analyses.

Average grain yield of the crosses was 0.4% greater than the parental populations themselves, whereas the time from planting to tasseling (-1.8%) and plant height (-3.0%) for the crosses were shorter than for the parental populations themselves (Table III). Grain yield among crosses ranged from 6017 kg/ha (Across 8528 x Pool 18) to 3041 kg/ha (Pool 16 x CMS 55). Crosses involving parents with white and yellow kernel colors were generally lower yielding, compared with crosses between yellow kernel parents.

Some of the better yielding crosses between yellow kernel parents included Across 8528 x Pool 18, Across 8528 x CMS 52, and Across 8528 x Tropical extra early yellow synthetic (Table III). Across 8528 x Pool 18 and Across 8528 x CMS 52 are dent x dent crosses whereas Across 8528 x Tropical extra early synthetic is a dent x flint cross. No relationship seemed to exist between endosperm type and heterosis expression. Our results do not agree with the results of Vassal *et al.* (1993), because they found that dent x flint crosses were generally higher yielding than dent x dent crosses.

No significant differences among crosses were observed by Vassal *et al.* (1993) because specific heterosis effect was not a significant component of heterosis. Some populations were better than others (Table III). Across 8528 had the greatest grain yield, followed by Pool 17 and CMS 55, which are yellow kernel types. Among white kernel color types Pool 16 and Pool 15 had similar yields. For days from time of planting to tasseling, Muneng 8531 and Pool 17 required the greatest number of days (58 days), whereas CMS 56 and CMS 47 were the earliest parents (53 days). For plant height, Muneng 8531 and Pool 17 were the tallest parents (209 cm) and CMS 56 (182 cm) and CMS 47 (188 cm) were the shortest parents.

Midparent heterosis for grain yield among the 105 crosses ranged from 29.4 to -35.9%. Approximately 52.3% of the values for midparent heterosis were positive, but the data suggest a lower frequency of favorable dominant alleles for yield among the populations. Most crosses involving CMS 47, a very early cycle and low yielding population, showed high levels of heterosis, with the exception of Pool 15 x CMS 47.

Across 8528 x CMS 52 and CMS 56 x Composto superprecoce canaforte were the tallest crosses, and

Table III - Means for grain yield of 15 early tropical maize populations and their crosses across 13 locations in Brazil, mid-parent heterosis for grain yield, and means for time from planting to tasseling and plant height.

Pedigree[a]	Grain yield (kg/ha)	Heterosis for yield (%)	Time to tassel (days)	Plant height (cm)
Crosses				
1 x 2	4642	-3.53	54	195
1 x 3	5533	15.45	58	203
1 x 4	4206	-4.45	52	189
1 x 5	4664	12.02	53	188
1 x 6	3981	-11.67	51	177
1 x 7	4937	6.76	54	197
1 x 8	4554	1.74	53	186
1 x 9	4064	-1.03	52	180
1 x 10	4763	10.24	55	199
1 x 11	4264	-8.26	55	199
1 x 12	5152	21.77	57	203
1 x 13	5065	11.38	56	196
1 x 14	4068	8.19	55	194
1 x 15	4827	27.06	54	201
2 x 3	4424	-14.82	54	192
2 x 4	6017	25.28	58	210
2 x 5	4082	-10.57	54	193
2 x 6	5346	8.92	55	204
2 x 7	4868	-3.13	54	190
2 x 8	5643	15.71	57	203
2 x 9	5459	21.11	56	197
2 x 10	4591	-2.98	55	196
2 x 11	5388	6.71	59	208
2 x 12	5442	17.49	58	209
2 x 13	5757	16.34	59	215
2 x 14	5101	9.44	60	212
2 x 15	5422	29.1	58	202
3 x 4	5314	11.09	58	214
3 x 5	4741	4.29	57	199
3 x 6	3602	-26.32	52	180
3 x 7	3955	-20.99	52	184
3 x 8	3769	-22.41	51	182
3 x 9	4374	-2.54	52	186
3 x 10	4242	-9.78	53	187
3 x 11	3853	-23.39	50	177
3 x 12	4299	-6.8	54	195
3 x 13	4363	-11.48	54	197
3 x 14	4089	-11.88	54	195
3 x 15	4207	0.63	52	191
4 x 5	4139	-0.37	54	190
4 x 6	4487	-0.24	54	199
4 x 7	3179	-31.12	51	180
4 x 8	4354	-2.53	53	189
4 x 9	3577	-12.7	51	175
4 x 10	4752	10.22	53	190
4 x 11	4166	-10.2	51	184
4 x 12	3965	-6.09	51	180
4 x 13	4243	-6.51	52	190
4 x 14	3952	-7.04	54	195
4 x 15	4839	27.68	54	203
5 x 6	4832	23.91	54	200
5 x 7	4462	11.08	55	198
5 x 8	4729	22.44	54	196
5 x 9	3607	3.09	52	187
5 x 10	3161	-14.89	51	167
5 x 11	4012	-0.71	52	180
5 x 12	3671	1.31	51	177
5 x 13	3649	-7.39	51	176
5 x 14	3527	-3.41	52	181
5 x 15	3687	15.53	52	176
6 x 7	4207	-10.88	51	187
6 x 8	3944	-13.74	52	181
6 x 9	4208	0.13	51	184
6 x 10	4135	-6.37	52	182
6 x 11	3041	-35.92	51	179
6 x 12	4516	4.37	53	188
6 x 13	4059	-12.59	54	187
6 x 14	3952	-9.25	52	184
6 x 15	4649	19.38	53	195
7 x 8	4241	-9.56	54	194
7 x 9	5389	24.75	55	203
7 x 10	4766	5.12	53	198
7 x 11	4769	-1.88	55	199
7 x 12	4742	6.69	53	195
7 x 13	4066	-14.6	53	186
7 x 14	4123	-7.81	53	192
7 x 15	3979	-0.83	51	186
8 x 9	4345	4.16	52	193
8 x 10	4304	-1.86	53	191
8 x 11	4879	3.52	55	202
8 x 12	4771	11.06	54	204
8 x 13	4278	-7.25	54	195
8 x 14	4413	2.06	54	189
8 x 15	3794	-1.81	53	193
9 x 10	3751	-6.62	51	173
9 x 11	4402	1.35	52	188
9 x 12	4537	15.52	54	189
9 x 13	4412	3.98	54	197
9 x 14	4261	7.78	52	189
9 x 15	4405	26.06	52	182
10 x 11	4617	1.31	52	192
10 x 12	3362	-18.8	51	179
10 x 13	4543	1.93	57	206
10 x 14	4463	7.06	53	202
10 x 15	4797	29.35	58	208

continued

Table III - Continued

Pedigree[a]	Grain yield (kg/ha)	Heterosis for yield (%)	Time to tassel (days)	Plant height (cm)
11 x 12	4392	-3.11	56	205
11 x 13	4575	-4.39	54	197
11 x 14	4301	-4.34	55	198
11 x 15	4137	2.5	55	195
12 x 13	4337	-0.7	55	199
12 x 14	4727	15.89	58	212
12 x 15	4589	26.8	56	207
13 x 14	4802	9.25	56	203
13 x 15	4429	12.54	53	196
14 x 15	3988	9.35	54	197
Means	4418		54	193
Parents				
1	4411	----	58	209
2	5213	----	57	212
3	5174	----	58	209
4	4393	----	54	206
5	3916	----	54	199
6	4603	----	56	203
7	4839	----	56	203
8	4541	----	56	203
9	3802	----	55	194
10	4231	----	54	189
11	4885	----	54	192
12	4052	----	53	188
13	4684	----	54	198
14	4107	----	55	197
15	3187	----	53	182
Means	4402		55	199
Checks	6270		60	200
LSD (0.05)	639		2.12	11.29

[a]See Table I for pedigree designation.

Tropical extra early yellow population x CMS 37 was the shortest cross. For time from planting to tasseling, the crosses were in a 10-day range from Across 8528 x Composto superprecoce canaforte to Pool 17 x CMS 55.

The populations Across 8528 and CMS 55 had some of the highest yields per se, and the highest and highly significant values for population effects (887.4 and 506.4 kg/ha), suggesting the presence of a higher frequency of favorable alleles compared with other populations.

Population Across 8528 had the highest, significantly negative population heterosis effect, which is because yield per se was better than its yield in crosses with the other populations. Muneng 8531, a lower yielding population, had highly significant positive values for population heterosis effects (884.6 kg/ha) and GCA effects (906.9), suggesting that Muneng 8531 has a frequency of favorable dominant alleles different from the other populations and has good general combining ability. Populations developed at CNPMS generally had better GCA effects than the populations developed at CIMMYT. CMS 47 had the lowest yield per se (3187 kg/ha) and had a highly significant negative value for GCA effects (-645.6).

For days from planting to tasseling, population effects were highly significant for all populations except Muneng 8531, Pool 16, Composto superprecoce canaforte, and CMS 47 (Table IV). Highly significant estimates for GCA effects were obtained for all populations, except Composto superprecoce canaforte. Negative values for population effects and GCA effects are desirable when earlier flowering is desired. Pool 17, Pool 18, Tropical extra early yellow synthetic, and CMS 47 had negative and significant estimates for GCA and population effects. This is an indication of a higher frequency of favorable alleles for earlier flowering. The largest positive value for population heterosis effect was for Muneng 8531 (9.8), and the largest negative value was for Pool 18 (-10.6) (Table IV).

For plant height, GCA and population effects were significant for the 15 populations. Pool 18 had the largest negative GCA effect (-12.53), while Tropical extra early yellow synthetic had the largest negative population effect (-17.3). The largest positive GCA effect was for Muneng 8531 (10.9), and the largest positive population effects (9.7) were for CMS 55 and Across 8528. Muneng 8531 had the largest highly significant positive population heterosis effect value (9.8), whereas the largest and highly significant negative value was for Pool 18 (-10.6).

Inbreeding depression

Inbreeding effects are known to maize breeders because of the research conducted by East (1908) and Shull (1908). Populations have different levels of tolerance to inbreeding. Some populations may collapse after a few generations of self-pollination while other populations tolerate homozygosity at higher levels and produce some useful inbred lines. Inbreeding depression for yield and other quantitative traits is a well known phenomenon and studies have been reported (Hallauer and Miranda Filho, 1988). Because the breeding schemes used on most tropical germplasms have not involved extensive inbreeding, it is very difficult to produce inbred lines with high levels of inbreeding that have acceptable yield levels. Inbreeding in maize reduces yield and components of

Table IV - Estimates of general combining ability effects (gi), populations effects (pi), and population heterosis effects (hi) for grain yield, time from planting to tasseling, and plant height for 15 early maize populations evaluated in Brazil.

Population	Grain yield			Time to tassel			Plant height		
	gi	pi	hi	gi	pi	hi	gi	pi	hi
1 - Muneng 8531	906.91**	-3.6	884.61**	3.39**	-0.20*	3.47**	10.93**	1.73**	9.81**
2 - Across 8528	-214.94**	887.40**	-682.74**	-0.99**	3.80**	-2.91**	-4.37**	9.73**	-9.49**
3 - Pool 17	-169.86**	-439.60**	25.84	-1.14**	-2.20**	-0.07	-3.85**	-4.26**	-1.95
4 - Pool 18	-498.01**	18.4	-531.32**	-2.53**	-1.20**	-1.95**	-12.53**	-4.14**	-10.64**
5 - Tropical extra early yellow population	-64.94	-664.60**	243.26**	-1.07**	-3.20**	0.51**	-5.14**	-17.27**	3.24**
6 - Pool 16	62.6	291.40**	-107.2	-0.68**	-0.20*	-0.61**	-1.37*	3.74**	-3.49**
7 - Pool 15	-146.40*	-91.6	-124.70*	-1.45*	-1.20**	-0.87**	-7.45**	-7.27**	-4.06**
8 - Tropical extra early yellow synthetic	-191.94**	-581.60**	74.76	-0.45**	-2.20**	0.62**	-1.99*	-13.25**	4.39**
9 - CMS 51	69.21	117.40**	-13.59	0.70**	0.80**	0.28	4.55**	5.73**	1.43
10 - CMS 37	81.69	-381.60**	248.37**	1.09**	0.79**	0.66**	6.09**	5.74**	2.97*
11 - CMS 55	301.68**	506.40**	24.37	1.93**	2.80**	0.51**	9.55**	9.73**	4.43**
12 - CMS 56	185.60**	419.4**	-48.2	0.70**	1.80**	-0.22	4.70**	2.74**	3.09**
13 - CMS 52	209.60**	-37.6	219.69**	0.86**	0.80**	0.40**	2.62**	0.72*	1.59
14 - Composto super-precoce canaforte	114.45**	181.40**	165.01*	0.16*	-0.20*	0.45**	2.45**	7.73**	0.63
15 - CMS 47	-645.63**	-221.60**	-378.17**	-0.53**	-0.21*	-0.27	-4.22**	-1.27**	-1.97

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

yield, reduces plant height, and increases time to flowering, creating problems in hybrid breeding (Vassal and Srinivasan, 1993). Inbreeding depression for plant height and for time from planting to tasseling was less drastic than for yield in our experiment because dominance effects were less important for these traits (Table V).

Estimates of inbreeding depression for different traits are not extensive (Hallauer and Miranda Filho, 1988). Differences in plant and ear trait losses with inbreeding are observed among the populations because different levels of selection were applied to the different populations. In our study, the inbreeding depression values ranged from about 16% to over 55% for yield, from -9.4% to -0.6% for time from planting to tasseling, and from 0.53% to 19.6% for plant height (Table V).

For these populations, S1 lines would be expected to average 1884 kg/ha less in yield, or 103 kg/ha decrease for each 1% increase in homozygosity. Also, S1 lines would be expected to be 19 cm shorter for plant height and 2.5 days later in maturity. Estimates of inbreeding depression (%) were negative for grain yield and plant height (decreases with inbreeding), but positive for time from planting to tasseling (increases

Table V - Inbreeding depression estimates (%) for grain yield, time from planting to tasseling, and plant height for 15 early maize populations evaluated in Brazil.

Population	Grain yield	Time to tassel	Plant height
1 - Muneng 8531	39.7	-3.4	13.9
2 - Across 8528	36.7	-5.3	12.7
3 - Pool 17	56.1	-5.2	19.1
4 - Pool 18	46.3	-1.8	13.6
5 - Tropical extra early yellow population	55.3	-5.6	19.6
6 - Pool 16	41.9	-0.6	17.7
7 - Pool 15	50.5	-0.8	13.3
8 - Tropical extra early yellow synthetic	53.1	-7.1	18.2
9 - CMS 51	35.1	-7.3	4.1
10 - CMS 37	46.4	-7.4	1.1
11 - CMS 55	47.9	-7.4	0.5
12 - CMS 56	35.8	-9.4	1.1
13 - CMS 52	16.5	-5.6	5.6
14 - Composto super-precoce canaforte	33.3	-0.8	5.1
15 - CMS 47	47.3	-1.9	8.8
Average	42.8	-4.6	9.4

with inbreeding). These results are similar to those reported by Genter (1971) and Harris *et al.* (1972). For most populations the contribution of the heterozygous loci was very high. From the results obtained, CMS 51, CMS 52, and Composto superprecoce canaforte seem to be the most promising populations for inbred line extraction.

Results from this study emphasize some points of interest in maize breeding. It was shown that additive gene effects were more important in controlling the expression of grain yield, time from planting to tasseling, and plant height. The lower levels of heterosis found among the earlier population crosses may be due to the lower levels of selection applied to them and (or) the presence of similar germplasm in the composition of the 15 populations included.

Improvement of yield performance of these early populations is possible. There is considerable potential for developing composites to use in an interpopulation recurrent selection program for hybrid development. For instance, Across 8528 x Pool 18 and CMS 37 x CMS 47 could be used in an interpopulation breeding scheme for hybrid production. To improve two populations and at the same time maximize the heterosis in crosses between them, CMS 47 and Across 8528 could be used for synthesis of one composite and CMS 37 and Pool 18 could be used to form the other composite.

RESUMO

Populações de milho de ciclo superprecoce são plantadas em áreas de estação curta de plantio e sua utilização vem crescendo gradualmente em regiões tropicais. O objetivo desse estudo foi o de determinar o potencial genético de 15 populações de milho de ciclo superprecoce através de um sistema de cruzamento dialélico. Este material genético foi formado por oito populações introduzidas do CIMMYT e sete populações sintetizadas no CNPMS. Foi utilizado um delineamento de látice triplo 12 x 12 e os ensaios foram avaliados em 13 ambientes no Brasil. A análise de variância conjunta para produção de grãos (PG), dias para o florescimento masculino (DFM) e altura de planta (AP) mostrou alta significância ($P < 0,01$) para tratamento, parental, heterose, heterose parental, heterose específica e interação de primeira ordem com ambiente. A heterose média foi significativa ($P < 0,01$) para DFM e não significativa para AP. A PG média variou de 3187 a 5213 kg/ha para as populações e de 3041 a 6017 kg/ha para os cruzamentos. As populações Pool 17 e CMS 52 apresentaram respectivamente o maior e o menor efeito de depressão por endogamia. O maior cruzamento específico para PG foi para Across 8528 x Pool 18. Nenhum dos cruzamentos foi superior aos híbridos comerciais testemunhas para os três caracteres estudados. Não houve associação entre tipo de endosperma e heterose. Os resultados sugerem que estas populações per se ou compostos sintetizados podem ser usados em programas de melhoramento de milho.

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