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Heterosis in maize single crosses derived from a yellow Tuxpeño variety in Brazil

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ABSTRACT

Most maize (*Zea mays* L.) crosses in tropical regions use the heterotic pattern of Tuxpeño dent and Caribbean flint. Crosses between related lines are not used for commercial production. Related inbred lines are used in either double or three-way hybrids with other unrelated lines to develop superior hybrids. This study was conducted to determine the combining ability among 11 related inbred lines from a Tuxpeño population. The 11 inbred lines were crossed in a diallel series and were evaluated at six locations. A combining ability analysis was made for grain yield. The average yield across environments for the 55 single crosses (44.8 q/ha) was not comparable to that of the single-cross hybrid (56.5 q/ha), included as check. General combining ability (GCA) effects and specific combining ability (SCA) effects were highly significant ($P < 0.01$). Variation due to GCA, however, accounted for 68% of the variation among crosses, indicating that additive genetic effects were more important than nonadditive effects. Highly significantly positive GCA effects were observed for lines 6 (2.44 q/ha) and 7 (6.40 q/ha) and highly significantly negative GCA effects for lines 5 (1.63 q/ha), 10 (2.64 q/ha), and 11 (4.01 q/ha). Significantly positive SCA effects were observed with line 4 x line 11, line 5 x line 9, and line 5 x 11 crosses. Lines 6 and 7 may have potential use as parents for three-way or double-cross hybrids.

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INTRODUCTION

The use of heterosis in maize breeding has been emphasized since Shull (1909) suggested the inbred-hybrid concept. The development of superior hybrids depends on the combining ability of lines involved in the production of the hybrids. Maize breeders, therefore, know that the probability of obtaining a highly heterotic hybrid is greater when the crosses are between unrelated lines than crosses between related lines (Hoegemeyer and Hallauer, 1976). Depending on the germplasm base and the breeding goals, the decision to produce either three-way or double-cross hybrids will include the use of related lines to produce heterotic hybrids.

Most of the cultivated maize hybrids in Brazil are crosses of lines with flint and dent germplasm (Paterniani, 1977). Hybrids between flint and dent lines are reported to be superior, both with respect to yield and to earliness in ripening (Brandolini, 1956; Cortez *et al.*, 1981). Several studies have been conducted to elucidate the heterotic patterns of maize populations (Naspolini Filho *et al.*, 1981; Darrah *et al.*, 1987; Miranda Filho and Vencovsky, 1984; Oyervides-Garcias *et al.*, 1985; Han *et al.*, 1991). In most instances, heterosis was too small to justify crosses between populations. Few

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results have been reported on heterosis expressed for grain yield in crosses of lines derived from within either dent or flint type maize populations (Vasal *et al.*, 1992). Further basic research on heterosis patterns should be conducted to obtain information on the development of single-cross hybrids that maximize the expression of heterosis.

The objective of this study was to evaluate the combining ability of a selected sample of related dent-type inbred lines extracted from a yellow kernel Tuxpeño population under selection for yield in the eastern region of Brazil.

MATERIAL AND METHODS

A tropical, early, yellow kernel Tuxpeño maize population introduced from CIMMYT in 1980 has been under half-sib family selection at the experimental station of Linhares - ES - Brazil, since 1982 (Ferrão, R.G., personal information). In 1990, 200 half-sib progenies were introduced and grown in progeny rows at the National Center for Corn and Sorghum Research (CNPMS) Sete Lagoas - MG - Brazil, and the two best plants from each row were self-pollinated. In the next season the 400 S_1 progenies were planted, self-pollinated, and the best 162 S_2 progenies were selected. The 162 S_2 progenies were planted in an isolated plot to cross with a known heterotic synthetic maize variety (CMS 50) as a male. The 162 topcrosses were evaluated using two 9 x 9 triple lattice design at seven locations. From the results of these trials, the 15 best S_3 lines were selected in accordance with their performance for yield and other agronomically desirable traits of the S_2 topcrosses. Later four of the 15 S_3 lines were discarded because of susceptibility to a leaf disease (*Phaeosphaeria maydis*).

The 11 S_3 lines were crossed in all possible combinations in the 1992 winter nursery at the CNPMS. Because similar yields have been reported for hybrids produced from lines with different levels of inbreeding in tropical maize (Borrero *et al.*, 1992) and in temperate maize (Carlone and Russell, 1988), the S_3 level of inbreeding was used in this study. The diallel series of crosses among the S_3 lines produced the 55 single-cross hybrids used in this trial.

The 55 single crosses and one commercial single-cross hybrids (HSBR201) were evaluated in a 7 x 8 triple rectangular lattice design at each of the six locations during the 1992 growing season. These locations were Ponta Grossa, PR (25.07 S, 50.10 W), Sete Lagoas, MG (19.28 S, 44.15 W), Janauba, MG (15.47 S, 43.18 W), Linhares, ES (19.24 S, 40.04 W), Pelotas, RS (31.45 S, 52.21 W), and Goiania, GO (16.6 S, 49.15 W). Because of the poor vigor of the inbred lines, they were included only in the diallel experiment at Sete Lagoas.

Plots included two rows that were 5 m long and planted at a density of 50,000 plants/ha. Data were taken on both rows for several agronomic traits, but in this report only data on grain yield are presented. Data for grain yield were analyzed using method 4, Model 1 (Griffing, 1956). For these analyses it was assumed that all factors were fixed except environment because lines were not a random sample. Combining ability analysis on data combined across locations was conducted to estimate genotype x environment interactions.

RESULTS AND DISCUSSION

Mean grain yield of the single crosses ranged from 58.6 q/ha at Ponta Grossa to 33.4 q/ha at Linhares. The commercial single-cross hybrid check yielded more than the best single cross at each location, but the difference was not significant at three locations (Table I). These results suggest that hybrids produced from unrelated lines have greater yields than from related lines (Hallauer and Miranda Filho, 1988).

Locations, crosses, and crosses x locations interac- tion sources of variation were highly significant ($P < 0.01$) (Table II). Crosses x locations interaction was highly significant, suggesting that the 55 hybrids did not have the same relative yields among locations. The best crosses were different among the six locations. The different ranks of hybrids among locations were because the location environments were different for temperature, humidity, rainfall, soil, etc. It is obvious, therefore, that specific high yielding single crosses are needed for each environment. Smaller genotype x environment interactions are expected for genetically broad-base populations than genetically narrow-base single crosses (Sprague and Eberhart, 1977; Wright *et al.*, 1971).

The combining ability analysis detected highly significant general combining ability (GCA) and specific combining ability (SCA) effects. The relative contribution of GCA and SCA sums of squares to the total sum of squares revealed that GCA accounted for 68% of the variation among crosses. GCA is important for inbred lines, and it suggests that this set of 11 inbreds should have good average performance in crosses. Previous studies have indicated that the additive genetic variance tends to be more important than nonadditive variance for grain yield (Gardner, 1963; Mariani and

Table I - Mean grain yield for 55 single crosses of 11 S_3 lines, best single cross between S_3 lines, and commercial single-cross hybrid (HSBR201) check for the six Brazil locations.

Location	Entry	Grain yield (q/ha)
Pelotas (RS)	Mean single cross	41.3
	Best single cross	50.3^{ns}
	Check	53.7
	LSD (0.05)	5.5
Janauba (MG)	Mean single cross	50.7
	Best single cross	70.2^{ns}
	Check	78.6
	LSD (0.05)	11.6
Ponta Grossa (PR)	Mean single cross	58.6
	Best single cross	78.6*
	Check	90.1
	LSD (0.05)	8.5
Goiania (GO)	Mean single cross	37.1
	Best single cross	48.3*
	Check	60.3
	LSD (0.05)	9.2
S. Lagoas (MG)	Mean single cross	47.9
	Best single cross	62.1*
	Check	70.7
	LSD (0.05)	6.4
Linhares (ES)	Mean single cross	33.3
	Best single cross	40.3^{ns}
	Check	46.2
	LSD (0.05)	7.2
Average	Mean single cross	44.8
	Best single cross	58.2^{ns}
	Check	66.5
	LSD (0.05)	8.8

*Different from the single-cross check at 0.05 probability level.
^{ns}Difference between best single cross and single-cross check was not significant.

Table II - Analysis of variance of diallel crosses among 11 tropical maize inbred lines for yield (q/ha) evaluated at six locations.

Source of variation	d.f.	Mean squares
Locations	5	86601.8**
Crosses	54	987.7**
GCA	10	3633.7**
SCA	44	386.4**
Loc x crosses	270	354.6**
GCA x loc	50	396.2**
SCA x loc	220	118.4
Error	648	183.0
CV (%)		5.3

**Significant at 0.01 probability level.

Desiderio, 1975). Although the parent lines were derived from one genetically broad-based population, the significant SCA effects suggest that there was adequate variation among lines for specific single crosses to deviate from the average performance of their parents in crosses.

The GCA x location interaction was highly significant, but the SCA x location interaction was not different from zero. Our results agree with those of Matzinger *et al.* (1959) who reported a greater interaction for GCA x location than for SCA x location interaction. Paroda and Hayes (1971) stated that the additive genetic component was more stable irrespective of the high rates of response to changes in environmental conditions. Presence of significant GCA and GCA x location effects suggests the need to select different parent lines for hybrids at individual locations. Also, significant GCA x location interaction may reflect small changes in rank for GCA effects that would not preclude identification of best lines for GCA (Pixley and Bjarnason, 1993).

The mean yield of each line in crosses, the estimates of GCA effects for each line, and estimates of SCA effects for the 55 crosses are listed in Table III. Line 7 had the highest mean yield in crosses and per se (Table III), but yield of line 7 per se was computed from only one location, Sete Lagoas. Line 11 had the poorest average yield in crosses but not as a parent per se (Table III). It seems that line 7 has a higher frequency of more favorable alleles fixed for yield than the other 10 lines used in this study.

Significantly positive and negative GCA effects were observed for the 11 lines. Han *et al.* (1991) also reported that lines derived from the same population may haver either good or poor general combining ability. Highly significant, negative GCA effects were observed for line 5, line 10 and line 11 (Table III), indicating that these parents contributed, on the average, to lower yields in the crosses. On the other hand, line 6 and line 7 showed significantly positive GCA effects.

The crosses line 10 x line 5 and line 11 x line 5 had the largest negative and positive SCA effects (Table III). Nearly half of the crosses (21 of 55) had negative SCA effects. These results are consistent with the

Table III - Means of 55 single (above diagonal), specific combining ability effects estimates (below diagonal), and general combining ability effects estimates for grain yield (q/ha) evaluated at six locations.

	1	2	3	4	5	6	7	8	9	10	11	Mean yield crosses	GCA
1	**12.6**[a]	42.6	46.3	45.1	45.4	46.9	54.5	45.2	43.1	42.9	42.9	45.5	0.93*
2	-2.63*	**7.7**	41.6	45.4	46.4	48.2	51.5	43.9	41.5	45.7	41.1	44.8	0.04
3	1.37	-2.74*	**9.1**	45.2	44.2	45.7	50.4	45.4	41.7	43.4	36.5	44.1	-0.63
4	0.85	0.41	1.07	**8.1**	42.5	46.8	47.4	44.4	44.3	41.7	42.6	44.5	-0.11
5	1.37	2.93*	2.26	-0.59	**4.6**	47.5	49.8	41.4	47.2	29.9	38.8	43.3	-1.63**
6	-1.37	0.85	-0.81	-0.33	1.85	**8.3**	55.5	46.7	45.5	44.8	42.6	47.1	2.44**
7	2.33*	0.22	0.22	-3.63**	0.55	1.81	**11.2**	50.5	51.9	50.6	43.5	50.6	6.41**
8	-0.74	-0.52	1.48	-0.04	-1.85	-0.26	-0.55	**9.2**	44.6	42.5	42.2	44.7	-0.18
9	-2.07	-2.53*	-2.18	0.29	4.81**	-1.59	1.44	0.37	**7.4**	42.4	41.2	44.4	-0.52
10	-0.18	3.70**	2.70*	-0.15	-11.63**	0.29	1.67	0.59	0.92	**3.8**	40.1	42.4	-2.74**
11	1.07	0.29	0.63	8.74**	11.15**	2.77	-1.31	0.81	0.52	2.07	**10.6**	41.2	-4.01**

*, **Significantly different from zero at 0.05 and 0.01 probability levels, respectively.
[a]Diagonal is mean yield (q/ha) of inbreds at one location. LSD (0.05) = 1.48 for mean yield.
Average yield of lines per se = 8.4 q/ha.
Average yield of crosses = 44.8 q/ha.

results of Han *et al.* (1991) and Vasal *et al.* (1992), who reported that, in general, more crosses produced by interpopulation lines have positive SCA effects, and crosses produced by intrapopulation lines tend to have more negative SCA effects. If SCA effects are an indication of the heterosis, the results suggest that genetic variability exists among these lines. Genetic diversity between two lines is related to heterosis, but lack of heterosis does not necessarily result from a lack of genetic diversity. Limited heterosis for crosses between lines from the same population could be due to the cancelling effects of different loci and alleles between two lines, and because the differences in allele frequency between the lines are not as great as for unrelated lines.

The results suggest that all single-cross hybrids were not suitable to be used per se, even when greater yield levels were achieved because of the environment effects on the checks. The single crosses should be used in crosses according to the heterotic patterns of breeding materials. The populations should be genetically variable within, but sufficiently different from each other so that a cross between selected lines from each population would give maximum heterotic effects for desirable trait, such as yield. In this way, the cancelling effects among the multiple loci and alleles could be avoided. If there are differences in alleles frequencies between lines at different loci, the probability of alleles being fixed in the lines will be differ- ent, and, therefore, crosses from lines of different origins would express, on the average, greater heterosis than lines having a similar origin (Hallauer and Miranda Filho, 1988). It will be advisable to intermate various breeding materials from different sources having superior yield and other desirable traits into this population to increase yield capacity and maintain all the available genetic variation for yield in the new composite population.

RESUMO

A maioria dos cruzamentos de milho (*Zea mays* L.) em regiões tropicais usam o modelo de heterose do dent Tuxpeño e flint Caribbean. Cruzamentos entre linhas não são usados para produção comercial. Cruzamentos de linhas parentais são usadas em híbridos duplos ou triplos com outras linhas para o desenvolvimento de híbridos superiores.

Este estudo foi conduzido para determinar a habilidade de combinação entre 11 linhas parentais da população Tuxpeño. Onze linhas parentais foram cruzadas em séries dialélicas e foram avaliadas em seis localidades. A análise de habilidade de combinação foi feita pela produção de grão. A média da produção através do desenvolvimento de 55 cruzamentos individuais (44,8 g/ha) não foi comparável com um cruzamento híbrido simples (56,5 g/ha) incluido como controle.

Efeitos da habilidade de combinação geral (GCA) e habilidade combinada específica (SCA) foram altamente significantes (P < 0,01). Entretanto, variação devido ao GCA contou por 68% da variação entre cruzamentos, indicando que efeitos genéticos aditivos foram mais importantes que os não aditivos.

Foram observados efeitos GCA significativamente positivos para linhas 6 (2,44 g/ha) e 7 (6,40 g/ha) e GCA

significativamente negativos para linhas 5 (1,63 g/ha), 10 (2,64 g/ha) e 11 (4,01 g/ha). Efeitos SCA significativamente positivos foram observados com linha 4 x linha 11, linha 5 x linha 9 e linha 5 x 11 cruzamentos. As linhas 6 e 7 devem ter potencial para uso como pais para híbridos de triplo ou duplo cruzamento.

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