HETEROSIS AND COMBINING ABILITY AMONG VARIETIES OF MAIZE IN ACID SOIL[1]

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ABSTRACT

Maize (*Zea mays* L.) cultivars tolerant to acidity and resistant to diseases have made the crop feasible in "cerrado" (savanna) soil. The identification of potentially useful germplasm with the above mentioned characteristics for breeding purposes was the objective of this study. Ten maize varieties (populations), previously selected for resistance to *Puccinia polysora*, *Phaeosphaeria maydis*, *Physopella zeae*, *Exserohilum turcicum* and corn stunt complex, were evaluated under the diallel crossing scheme. Varieties and crosses were evaluated in acid and low fertility soil. Analyzed traits were: ear yield (EY), plant height (PH), and ear height (EH). Varieties PMI 8701, CMS 57NF, PMI 9401 CMS 58ND and AMARILLO DENTADO DMR showed the highest yields (above 3.5 t/ ha) per se representing more than 70% in relation to check yield. Heterosis showed significance for all traits, but among the components of heterosis only average heterosis was significant for EY and specific heterosis for EH. General combining ability effects (g_i) were significant for all traits, and their highest EY estimates (t/ha) were for PMI 8701 (0.150), BR 105 (0.120), CMS 59 (0.106). The cross CMS 57NF x PMI 8701, with yield of 5.11 t/ha (above both hybrid checks) and heterosis of 23.7% above mid-parent, may be indicated as a potentially useful heterotic group. Varieties PMI 8701, CMS 57NF, PMI 9401 and CMS 58ND were considered the most promising intrapopulation breeding programs, for acid soils.

KEY WORDS: Heterosis, acidity stress, combining ability, germplasm.

RESUMO

HETEROSE E CAPACIDADE COMBINATÓRIA ENTRE VARIEDADES DE MILHO EM SOLO ÁCIDO

Cultivares de milho (*Zea mays* L.) com tolerância à acidez e resistência a doenças têm viabilizado o cultivo em solos sob vegetação de cerrado. A identificação de germoplasma com potencial para o melhoramento, com essas características, foi o objetivo deste estudo. Dez variedades de milho, resistentes a *Puccinia polysora*, *Phaeosphaeria maydis*, *Physopella zeae*, *Exserohilum turcicum* e complexo enfezamento, foram avaliadas em cruzamentos dialélicos. As variedades e seus híbridos foram avaliados em solo ácido e com baixa fertilidade. Os caracteres analisados foram: peso de espigas (PE), altura da planta (AP) e altura da espiga (AE). As variedades PMI 8701, CMS 57NF, PMI 9401, CMS 58ND e AMARILLO DENTADO DMR, *per se*, produziram acima de 3,5 t/ha, o que equivale a mais de 70% em relação à testemunha. A heterose foi significativa para PE, AP e AE, e, entre seus componentes, também o foram a heterose específica para AE e a heterose média para PE. Os efeitos de capacidade geral de combinação (g_i) foram significativos para todos os caracteres, e suas maiores estimativas para PE (t/ha) foram as de PMI 8701 (0,150), BR 105 (0,120) e CMS 59 (0,106). O híbrido interpopulacional CMS 57NF x PMI 8701, com produção média de 5,11 t/ha e 23,7% de heterose, pode ser indicado como um grupo heterótico potencial. As variedades PMI 8701, CMS 57NF, PMI 9401 e CMS 58ND foram consideradas promissoras para programas de melhoramento intrapopulacional nas condições de solo ácido.

PALAVRAS-CHAVE: Heterose, estresse de acidez, capacidade de combinação, germoplasma.

INTRODUCTION

Soils under "cerrado" vegetation represent approximately 150 million hectares in Brazil (Embrapa 1978), with the characteristics of acidity and low fertility (Lopes 1983). Acidity associated with toxic aluminum and low availability of nutrients cause reductions in the development of the root system, in the tolerance to water stresses and in the absorption of nutrients by maize (*Zea mays* L.), limiting the yield potential of the plants (Olmos & Camargo 1975, Foy *et al.* 1978, Ritchie 1989). In addition, severe leaf

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diseases caused by *Puccinia polysora*, *Physopella zeae* and *Phaeosphaeria maydis* have occurred in the "cerrado" soils of the central region of Brazil after 1990, becoming a limiting factor on maize crops (Pereira 1995).

As a consequence of the limitations of acid soils and diseases on maize crops, the development of cultivars adapted to those conditions has been an important strategy in breeding programs. Therefore, using adequate base populations with good expression of the mean and variance of important quantitative traits increases the chances for success of breeding programs. Following this trend, some studies have been conducted for the identification of germplasm sources potentially tolerant to acid soils (Bahia Filho *et al.* 1976, Naspolini Filho *et al.* 1981, Eleutério *et al.* 1988, Lima *et al.* 1992, Pandey *et al.* 1994, Salazar *et al.* 1997) and resistant to diseases (Zoccoli *et al.* 1996, Ferreira 1999, Mesquita Neto 2000; Miranda Filho *et al.* 2000).

Among the methodologies for the identification of potentially useful germplasm, the diallel cross has been widely used, allowing the evaluation of varieties or genotypes *per se* and in crosses (Miranda Filho & Gorgulho 2001).

This study investigated the potential *per se* and in crosses, for tolerance to the conditions of acid soil with nutritional limitations, of ten open-pollinated varieties, previously selected for resistance to leaf diseases.

MATERIAL AND METHODS

The NAP-MILHO (Núcleo de Apoio à Pesquisa do Milho - ESALQ/USP) organized experiments conducted in nine locations in 1994-1995 with 140 improved varieties (populations) for identification of sources for resistance to a *Puccinia polysora*, *Phaeosphaeria maydis*, *Physopella zeae*, *Exserohilum turcicum* and corn stunt complex (Ferreira 1999, Miranda Filho *et al.* 2001). Ten varieties were selected, firstly for resistance to *Puccinia polysora* and secondly for the other diseases; for their identification we have used the same symbols as used by Ferreira (1999) and is shown in Table 1.

In 1995-1996, the parent varieties were multiplied by sib-mating and crossed following the complete diallel mating scheme, using paired row (10 m long) each row.

The diallel set (10 varieties and 45 crosses) were evaluated in 1997-98 in the Experiment Station of Anhembi (SP), following a completely randomized block design with four replications. Two-row plots 4.0 m long and spaced 0.90 m, apart were used, with an expected stand of 40 plants per plot after thinning. Two hybrid checks were intercalated every 7 plots or 14 rows. Checks were previously chosen for a pattern of tolerance to acid soil: AG 6601 and AG 5011, considered as sensitive and tolerant, respectively. The experimental area is characterized by its acid soil and low fertility. Its chemical composition has already been reported by Morello *et al.* (2001).

Before planting, fertilization followed approximately the quantities (kg/ha): 16 N, 56 P2O5 and 32 K2O. Other cultural practices and procedures followed technical recommendations for the maize crop.

The following traits were evaluated: PH- plant height (cm), EH- ear height (cm), and EY- ear yield (t/ha); EY was adjusted to a stand of 40 plants per plot through the analysis of covariance of yield on stand variation (Vencovsky & Barriga 1992).

Means (over replications) of varieties and variety crosses were analyzed according to model 4, analysis II of Gardner & Eberhart (1966), or:

$$Y_{ii'} = \mu + \tfrac{1}{2}(v_i + v_{i'}) + \theta(\bar{h} + h_i + h_{i'} + s_{ii'}) + \bar{e}_{ii'}$$

In the model, $Y_{ii'}$ is the mean of a parental variety (i = i'; θ = 0) or a variety cross (i < i'; θ = 1); μ is the mean of the parent varieties; v_i is the fixed effect of the i^{th} variety; $\bar{h}$ is the average mid-parent heterosis of all crosses; h_i is the effect of variety heterosis; $s_{ii'}$ is the effect of specific heterosis; and $\bar{e}_{ii'}$ is the error term associated with the mean. Estimates of the effects in the model were obtained, as well as the effect of general combining ability (GCA) through the relation $g_i = \frac{1}{2}v_i + h_i$. Both the estimation of effects and the analysis of variance for testing hypothesis were performed according to Gardner (1967).

RESULTS AND DISCUSSION

Among the varieties evaluated *per se*, means for ear yield (EY) were in the range of 2.64 t/ha to 4.52 t/ha (Table 2) and varieties PMI 8701, CMS 57NF, PMI 9401 CMS 58ND and AMARILLO DENTADO DMR showed the highest yields (above 3.5 t/ha), representing more than 72% in relation to the yield of both checks (AG 6601 and AG 5011). Means of plant height (PH) and ear height (EH) were between 165 cm to 214 cm and 94 cm to 128 cm,

Table 1. Identification of improved varieties (populations) from the NAP-MILHO Project selected for disease resistance (Ferreira 1999)

Population code	Identification	Population code	Identification
NAP 21	BR 105	NAP 75	Amarillo Dentado DMR
NAP 47	CMS 57 NF	NAP 97	IAPAR 51
NAP 48	CMS 58 ND	NAP 105	PMI 8701
NAP 49	CMS 59 Sintético Elite	NAP 114	PMI 9401
NAP 66	WP 12	NAP 128	ESALQ (PB2xPB3) B[1]

[1]- ESALQ (PB2xPB3) B: obtained by recombination of the cross ESALQ PB2 x ESALQ PB3, selected for white kernels.

showed the highest means, while the lowest PH and EH were for CMS 59 and IAPAR 51, respectively (Table 2).

Variety crosses yielded 0.683 t/ha more than the parental varieties, on average; outstanding crosses were V7 x V9 (CMS 57NF x PMI 8701) and V1 x V10 (BR 105 x PMI 9401) with yields above 4.8 t/ha, approximately at the same level as the hybrid checks. Means of PH and EH in the variety crosses were between 173 cm and 204 cm and 88 cm and 126 cm, respectively (Table 3). In general, yield levels in the present study were relatively low, which is justified by the stress condition (soil acidity and low fertility) of the experiment. The same set of varieties and crosses were evaluated by Ferreira (1999) in Ribeirão Preto (SP) and Rio Verde (GO), under normal conditions of acidity and fertility, showing average yields of 6.95 t/ha and 6.77 t/ha, respectively. PH and EH also were substantially higher in the experiments of Ribeirão Preto (SP) and Rio Verde (GO) (Ferreira 1999). Variation due to different locations and years is expected, but the lower stresses attributed to acidity and low fertility. Clark (1977), Gonzales-Erico *et al.* (1979), Naspolini Filho *et al.* (1981) and Bennet *et al.* (1986) also emphasized the effect of acidity associated with aluminum saturation and low nutrient availability on the lower expression of quantitative traits.

The highest heterosis effect (2 t/ha) was observed in the cross CMS 59 x WP 12, corresponding to 75% above mid-parent. Other heterotic crosses, with heterosis above 1 t/ha (more than 30% over mid-parent), were BR 105 x CMS 39, BR 105 x PMI 9401, [CMS 59 x (ESALQ PB2 x ESALQ PB3)], CMS 59 x PMI 9401, [AMARILLO DENTADO DMR x (ESALQ PB2 x ESALQ PB3)], AMARILLO DENTADO DMR x IAPAR 51 and CMS 57NF x IAPAR 51 (Table 3). The identification of heterotic pairs allows the exploitation of the genetic divergence between parental varieties, either for the development of inbred lines to be used in hybrid crosses or for the synthesis of pairs of composites with a high heterotic pattern (Hallauer & Miranda Filho 1995).

Table 2. Observed means of parental varieties for plant height (PH), ear height (EH) and total ear yield (EY) – Anhembi (SP), Brasil, 1997-1998

Symbology	Varieties	PH	EH	EY		
		(cm)	(cm)	t/ha	% CH1[1]	% CH2
V_1	BR 105	182	104	3.48	71.7	71.4
V_2	CMS 58ND	199	111	3.68	75.8	75.5
V_3	CMS 59	165	98	2.67	55.0	54.8
V_4	WP 12	214	128	2.67	54.4	54.2
V_5	AMARILLO DENTADO DMR	174	98	3.53	72.7	72.4
V_6	ESALQ PB2 x ESALQ PB3	179	99	3.21	66.1	65.9
V_7	CMS 57NF	183	96	3.74	77.1	76.8
V_8	IAPAR 51	183	94	3.19	65.7	65.5
V_9	PMI 8701	184	101	4.52	93.2	92.8
V_{10}	PMI 9401	202	124	3.71	76.4	76.1
-	Average	186	105	3.43	70.8	70.5
CHECK 1	AG 6601	164	84	4.85	-	-
CHECK 2	AG 5011	185	108	4.87	-	-

[1]- %CH1 and %CH2: ear yield in percent of checks 1 and 2, respectively.

Table 3. Means of variety crosses for plant height (PH), ear height (EH) and ear yield (EY) and estimates of mid-parent heterosis (h) – Anhembi (SP), Brazil, 1997-1998

Crosses[1]	PH (cm)	EH (cm)	EY				
			t/ha	% CH 1[2]	% CH 2	h	h%[3]
V_1 x V_2	193	102	4.47	92.1	91.7	0.89	24.8
V_1 x V_3	174	101	4.36	89.9	89.5	1.29	41.7
V_1 x V_4	201	117	3.83	78.9	78.6	0.77	25.1
V_1 x V_5	186	97	3.76	77.5	77.2	0.26	7.2
V_1 x V_6	195	122	4.09	84.3	83.9	0.75	22.2
V_1 x V_7	179	88	4.03	83.0	82.7	0.42	11.6
V_1 x V_8	196	111	4.30	88.6	88.3	0.97	28.9
V_1 x V_9	186	96	4.36	89.9	89.5	0.36	9.0
V_1 x V_{10}	194	108	4.86	100.2	99.7	1.27	35.1
V_2 x V_3	183	100	4.06	83.6	83.3	0.88	27.8
V_2 x V_4	199	111	3.77	77.7	77.4	0.61	19.3
V_2 x V_5	186	99	3.89	80.2	79.8	0.29	7.9
V_2 x V_6	196	111	4.03	83.0	82.7	0.59	16.9
V_2 x V_7	180	93	3.92	80.8	80.4	0.21	5.6
V_2 x V_8	191	103	4.19	86.3	86.0	0.76	21.9
V_2 x V_9	177	88	4.10	84.5	84.1	0.00	0.0
V_2 x V_{10}	200	108	4.04	83.3	82.9	0.35	9.3
V_3 x V_4	194	118	4.65	95.8	95.4	2.00	75.1
V_3 x V_5	173	96	3.59	74.0	73.7	0.49	15.8
V_3 x V_6	184	108	4.69	96.7	96.3	1.75	59.5
V_3 x V_7	176	99	4.13	85.1	84.8	0.93	28.8
V_3 x V_8	180	93	4.24	87.4	87.0	1.31	44.7
V_3 x V_9	188	117	3.81	78.5	78.2	0.22	5.9
V_3 x V_{10}	192	118	4.41	90.9	90.5	1.22	38.2
V_4 x V_5	176	96	3.15	64.9	64.6	0.06	2.1
V_4 x V_6	198	116	3.48	71.7	71.4	0.56	18.9
V_4 x V_7	204	116	3.56	73.4	73.1	0.37	11.6
V_4 x V_8	204	114	3.51	72.3	72.0	0.60	20.4
V_4 x V_9	201	113	3.93	81.0	80.7	0.35	9.7
V_4 x V_{10}	203	126	3.74	77.1	76.8	0.57	17.8
V_5 x V_6	194	117	4.56	94.0	93.6	1.19	35.3
V_5 x V_7	173	95	4.17	85.9	85.6	0.54	14.7
V_5 x V_8	188	109	4.67	96.2	95.8	1.31	38.9
V_5 x V_9	186	103	4.46	91.9	91.5	0.44	10.8
V_5 x V_{10}	194	121	4.25	87.6	87.2	0.63	17.4
V_6 x V_7	183	100	4.12	84.9	84.6	0.65	18.5
V_6 x V_8	191	106	3.98	82.0	81.7	0.78	24.3
V_6 x V_9	186	96	4.35	89.6	89.3	0.49	12.5
V_6 x V_{10}	182	103	3.78	77.9	77.6	0.32	9.2
V_7 x V_8	179	103	4.73	97.5	97.1	1.27	36.5
V_7 x V_9	182	98	5.11	105.3	104.9	0.98	23.7
V_7 x V_{10}	186	106	3.98	82.0	81.7	0.26	6.8
V_8 x V_9	189	99	3.91	80.6	80.2	0.06	1.4
V_8 x V_{10}	188	99	4.16	85.7	85.4	0.71	20.5
V_9 x V_{10}	189	106	4.26	87.8	87.4	0.15	3.5
Average	188	105	4.12	84.9	84.5	0.68	20.8
CHECK 1	164	84	4.85	-	-	-	-
CHECK 2	185	108	4.87	-	-	-	-

[1]- Symbology (see Table 2); 2- %CH1 and %CH2: ear yield in percent of checks 1 and 2, respectively; 3- h%: heterosis in perent of mid-parent.sforo.

The analyses of variance of the diallel tables (Table 4) indicated significance for the effects of varieties, total heterosis and general combining ability for PH, EH and EY. From the heterosis components, significance was detected only for average heterosis for EY and specific heterosis for EH; for EY, means for varieties and crosses were 3.43 t/ha and 4.12 t/ha, respectively. The non-significance of variety heterosis and specific heterosis for EY indicate that the identification of the best varieties, respective to their genetic values, can be accomplished through the effects of varieties *per se*. For that reason, the significance of general combining ability (GCA) for EY is attributed to the effects of varieties.

Significant heterotic effects, particularly for specific heterosis, is not common for PH and EH (Miranda Filho & Vencovsky 1984), so the results observed in this work for EH can be attributed to non-additive effects in some particular crosses.

The non-significance for the variation in the components of heterosis indicates that the discrimination among varieties for EY in relation to their genetic values can be based only on variety effects (v_i). The highest v_i estimates for EY (t/ha) were for PMI 8701 (1.083), CMS 57NF (0.303), PMI 9401 (0.273) and CMS 58ND (0.243) (Table 5). Varieties CMS 57NF and CMS 58ND also were considered as outstanding under the conditions of normal soil (Santos *et al.* 1994, Ferreira 1999).

Machado *et al.* (1996) also pointed out the superiority of CMS 57NF and CMS 58ND when evaluated *per se* under the conditions of low fertility. It is worthwhile to point out that populations CMS 57NF and CMS 58ND originated from ESALQ VD8 and ESALQ VF7, respectively, through recurrent selection under adverse conditions, mainly low levels of nitrogen (Machado & Paterniani 1994). For PH and EH varieties WP 12, PMI 9401 and CMS 58ND showed positive estimates of v_i, which is not appropriate for tropical conditions if there is interest in shorter plants (Miranda Filho & Vencovsky 1984; Paterniani 1990).

Table 4. Mean squares[1] of the analysis of variance for plant height (cm), ear height (cm) and ear yield (t/ha) following the model of diallel cross (Gardner & Eberhart 1966) – Anhembi (SP), Brazil, 1997-1998

Source	d.f.	Plant height	Ear height	Ear yield (x10^3)
Entries	54	96.846**	96.361**	248.241**
Varieties	9	386.292**	296.125**	383.736**
Heterosis	45	38.957*	56.408**	221.142**
Average heterosis	1	30.231^{ns}	0.227^{ns}	3826.670**
Variety heterosis	9	42.674^{ns}	45.824^{ns}	154.916^{ns}
Specific heterosis	35	38.250^{ns}	60.735**	135.156^{ns}
Error	162	25.819	29.269	105.131
General combining ability	9	220.244**	199.938**	233.674*

[1]- Analysis with means over four replications.

Table 5. Estimates of the variety mean ($\hat{\mu}$), average heterosis ($\bar{h}$) and effects of varieties (v_i), variety heterosis (h_i) and general combining ability (g_i) for plant height (cm), ear height (cm) and ear yield (t/ha) following the model of diallel crosses (Gardner & Eberhart 1966) – Anhembi (SP), Brazil, 1997-1998

Varieties	Plant height			Ear height			Ear yield		
	$\hat{v}_i$	$\hat{h}_i$	$\hat{g}_i$	$\hat{v}_i$	$\hat{h}_i$	$\hat{g}_i$	$\hat{v}_i$	$\hat{h}_i$	$\hat{g}_i$
BR 105	-4.50	3.27	1.02	-1.30	-0.25	-0.90	0.043	0.100	0.121
CMS 58ND	12.50	-5.10	1.15	5.70	-7.12	-4.27	0.243	-0.198	-0.077
CMS 59	-21.50	4.27	-6.47	-7.30	3.75	0.10	-0.767	0.490	0.106
WP 12	27.50	-3.22	10.52	22.70	-1.62	9.72	-0.797	-0.035	-0.433
AMARILLO DENT. DMR	-12.50	1.27	-4.97	-7.30	1.62	-2.02	0.093	-0.120	-0.073
ESALQPB2 x ESALQPB3	-7.50	5.40	1.65	-6.30	6.87	3.72	-0.227	0.112	-0.001
CMS 57NF	-3.50	-4.97	-6.72	-9.30	-1.75	-6.40	0.303	-0.068	0.082
IAPAR 51	-3.50	3.02	1.27	-11.30	4.12	-1.52	-0.247	0.198	0.075
PMI 8701	-2.50	-0.22	-1.47	-4.30	-2.00	-4.15	1.083	-0.391	0.150
PMI 9401	15.50	-3.72	4.02	18.70	-3.62	5.72	0.273	-0.087	0.049
$\hat{\mu}$		186.50			105.30			3.437	
$\bar{h}$		1.92			0.16			0.683	

Variety heterosis effects (h_i) for EY (t/ha) varied from -0.391 to 0.490 (Table 5) but showed non-significance. GCA effects (g_i) for EY showed significance (Table 5) and the largest estimates were 0.150, 0.121 and 0.106 for PMI 8701, BR 105, and CMS 59, respectively. For PH and EH negative g_i estimates were shown by CMS 59 e CMS 57NF, which can be considered adequate if there is interest in short plant architecture.

CONCLUSIONS

1. For the acid soil conditions, the varieties PMI 8701, CMS 57NF, PMI 9401 and CMS 58ND can be indicated as bases for intrapopulation selection.
2. Discrimination based on GCA effects indicates PMI 8701, BR 105, CMS 59, CMS 57NF, IAPAR 51 and PMI 9401 as potentially useful for the synthesis of new composites.
3. Some pairs of varieties can be indicated as heterotic groups for the development of inbred lines to be used in hybrid crosses. An outstanding cross is CMS 57NF x PMI 8701, with superiority over the hybrid checks AG 6601 and AG 5011.

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