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COMBINING ABILITY OF MAIZE LINES IN TOP CROSSES WITH NARROW GENETIC BASE TESTERS[1]

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ABSTRACT - The objectives were to study the combining ability of 30 lines from the maize breeding program of Instituto Agronômico, Sao Paulo State, (SP), Brazil, in top crosses schemes. The 30 lines and two testers (single cross hybrids) were crossed to obtain the 60 top crosses that were evaluated, with three commercial hybrids (checks), in two locations, Mococa and Campinas, in 2001/02, using a randomized complete block design with three replications. The following agronomic traits were evaluated: Plant height (PH), ear height (EH), lodged and broken plants (Ld + Br), and grain yield (GY) corrected to 14% moisture. The combining ability of the lines was estimated according to the Griffing's Method 2 (1956), adapted for partial diallels. The Mean Squares presented a significant ($P < 0.01$) effect for Lines and Lines /Tester in all the characters, except (Ld + Br) in Mococa, showing additive effects in their control. The cross effects were significant ($P < 0.01$) for all characteristics in Mococa and only for EH and GY in Campinas. The interaction effect (Tester x Line) was significant in Mococa ($P < 0.01$), indicating that non-additive effects for PH, EH and GY were important too. A significant number of three way cross presented GY similar to the checks. The lines L 10, L 156, L 126, L 111, SLP 103 and IP 330 were outstanding for general combining ability and should be useful in maize breeding programs in tropical conditions.

Key words: *Zea mays*, combining ability, top cross, testers, grain, three-way crosses.

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CAPACIDADE DE COMBINAÇÃO DE LINHAGENS DE MILHO EM TOP CROSSES COM TESTADORES DE BASE GENÉTICA RESTRITA

RESUMO - Com o intuito de testar linhagens de milho do programa de melhoramento do Instituto Agronômico (IAC) quanto à capacidade de combinação e obter híbridos triplos com elevado potencial produtivo, 30 linhagens foram cruzadas em esquemas top crosses com dois testadores (híbridos simples-elite experimentais). Os 60 top crosses, (híbridos triplos) resultantes foram avaliados em dois locais, Mococa e Campinas, em 2000/2001, em dois ensaios (TC 1 e TC 2), sob delineamento de blocos ao acaso, com três repetições, contendo ainda, o respectivo testador e três testemunhas comerciais (AGN 2012 , BR 3123 e C 333B). Foram avaliados os seguintes caracteres agronômicos: altura da planta (AP) e altura da espiga (AE); plantas acamadas e quebradas (Ac + Que) e peso de grãos corrigido para 14% de umidade (PG). A capacidade de combinação das linhagens foi estimada de acordo com o Método 2 de Griffing (1956), adaptado para dialelo parcial. Os Quadrados Médios foram significativos (P < 0,01) para os efeitos de Linhagens e de Linhagens/Testador, em todos os caracteres, exceto (Ac+ Que) em Mococa, evidenciando a manifestação de efeitos aditivos. O efeito de cruzamentos foi significativo para todos os caracteres, em Mococa, e para AE e PG, em Campinas. O efeito da interação (Testador x Linhagem) foi significativo em Mococa, indicando efeitos não aditivos no controle de AP, AE e PG. Um número expressivo de híbridos triplos apresentou produtividade similar à das testemunhas comerciais. As linhagens L 10, L 156, L 126, L 111, SLP 103 e IP 330 destacaram-se quanto à capacidade geral de combinação e poderão ser úteis em programas de melhoramento de milho em condições tropicais.

Palavras-chave: milho, top cross, testadores, capacidade de combinação, híbridos triplos.

The hybrid vigor is one of the greatest contributions of genetics to the agricultural world and had its most significant expression in maize crops (Paterniani, 2001). Commercial maize hybrid production requires methods to test lines in hybrid combinations, which is the most important and expensive step and that requires experimental accuracy.

The line evaluation in diallel designs proposed by Griffing (1956 a and b) is based on the concepts of general and specific combining ability established by Sprague & Tatum (1942). These authors defined general combining ability (GCA) as the average performance of a line in hybrid combinations and specific combining ability (SCA) as a performance of hybrid combinations that are either better or poorer compared to the average performance of the inbred lines involved. Also, they interpreted GCA as an indication of genes having significant additive effects and SCA as indicative of genes having dominance and epistatic effects. The diallel cross is widely used by breeders to test lines in hybrid combinations , but in practice it limits the number of lines used, requiring much effort in manual pollination to obtain all the desired crosses.

In a further attempt to increase efficiency and simplify line evaluation in hybrid programs, the top crosses method was proposed by Davis (1927), which consists of crossing lines with a common tester to be assessed in experiments with replications. The objective of this method is to assess the relative merits of the lines in crosses

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with testers, eliminating those with inferior agronomic performance, making the hybrid program more rational and efficient (Radovic & Jelovac, 1995; Eyhérabide & Gonzalez, 1997; Nurmberg *et al*., 2000; Santos *et al*., 2001). Top crosses to assess lines in hybrid maize programs have been used because they are easy, efficient and reliable. However, the choice of a tester that promotes better discrimination among the lines according to the purposes of selection persists and it is the subject of studies and discussions (Aguilar Moran, 1984; Aguilar Moran, 1990; Hallauer & Miranda Filho, 1995; Castellanos *et al*., 1998; Santos *et al*., 2001).

Generally, both theoretical studies and experimental evidence are in favor of the superiority of a recessive homozygote tester or a variety with low frequency of favorable alleles. This tester will enable easier identification of lines with greater favorable allele frequencies (Miranda Filho & Viégas , 1987; Hallauer & Miranda Filho, 1995). In practice, testers are chosen empirically using elite materials from company programs, based on previous field results, and attempting to identify lines that have a high combining ability with a given population or single hybrids.

Thus the objectives of the present study were to ascertain the efficiency of narrow genetic base testers in line discrimination; estimates of the combining ability of lines from the IAC maize breeding program and evaluate the performance of three-way cross maize hybrids resulting from top crosses in two locations in São Paulo State, Brazil.

Material and Methods

The summary description of lines used in this work is shown in Table 1 and it is divided into two groups: Group I, comprising 22 CIMMYT lines previously introduced in the maize breeding program of IAC; and Group II, represented by 8 lines of IAC germplasm from diverse origins and populations. The 22 lines of Group I are younger and have a lower plant height and the 8 lines of Group II from IAC are old, tall and normal to late cycle. These thirty maize lines were crossed with two experimental single cross hybrids, named tester 1 (IAC 21) and tester 2 (IAC 101.121). The testers 1 and 2 were obtained from crossing of lines of CIMMYT.

The resulting 60 top crosses (three-way cross), with three commercial checks (C 333 B, AGN 2012 and BR 3123) were evaluated in 2001/2002, in Campinas Experimental Center at IAC and in the Mococa Regional Polo, using two experiments, TC 1 and TC 2. A randomized complete block design was used with three replications; each plot with two-row, 5 m long, dispersed at 0.90 x 0.20 m between and within rows. The fertilizations used were 250 kg ha^{-1} (8-28-16) and 250 kg ha^{-1} ammonia sulfate in Campinas and 400 kg ha^{-1} (08-28-16) and 200 kg ha^{-1} (20-05-20) using two side dressings in Mococa.

Data were collected for the following traits: plant height (PH) and ear height (EH) of five competitive plants per plot, in cm; number of lodged and broken plants (Ld + Br); grain yield (GY): total grain weight of the plot, in kg ha^{-1} and grain moisture, after corrected to 14% moisture.

Preliminary analysis of variance for each experiment and combined analysis over experiments were performed for all traits. The analysis of variance of the partial diallel tables combined over experiments followed the model by Griffing (1956a) for estimating the general combining ability of the lines. Tukey test at 5% was used to compare the means. The number of lodged and broken plants (Ld + Br) values were transformed in $\sqrt{x+0.5}$. The testers were

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TABLE 1. Maize lines and testers used in the top crosses Campinas, SP, Brazil, 2001/2002.

Order number	Denomination	Origin	Grain type	Grain color
1	L 3	CIMMYT	Semiflint	Yellow
2	L 4	CIMMYT	Dent	Yellow
3	L 5	CIMMYT	Flint	Orange
4	L 6	CIMMYT	Flint	Orange
5	L 8	CIMMYT	Dent	Yellow
6	L 9	CIMMYT	Dent	Orange
7	L 10	CIMMYT	Dent	Yellow
8	L 13	CIMMYT	Flint	Orange
9	L 14	CIMMYT	Flint	Orange
10	L 15	CIMMYT	Dent	Yellow
11	L 111	CIMMYT	Flint	Orange
12	L 117	CIMMYT	Dent	Yellow
13	L 126	CIMMYT	Semident	Yellow
14	L 130	CIMMYT	Semiflint	Orange
15	L 156	CIMMYT	Semident	Orange
16	L 160	CIMMYT	Dent	Yellow
17	L 161	CIMMYT	Semiflint	Orange
18	L 162	CIMMYT	Dent	Yellow
19	L 168	CIMMYT	Semident	Yellow
20	L 169	CIMMYT	Dent	Yellow
21	L 170	CIMMYT	Flint	Orange
22	L 171	CIMMYT	Dent	Yellow
23	AL 218	IAC	Flint	Orange
24	AL 326	IAC	Flint	Orange
25	AL 11	IAC	Flint	Orange
26	AL 628	IAC	Flint	Orange
27	IP 330	IAC	Dent	Yellow
28	SLP 103	IAC	Flint	Orange
29	IP 701	IAC	Dent	Yellow
30	IP 4035	IAC	Dent	Yellow
31	Tester 1	IAC	Semiflint	Yellow
32	Tester 2	IAC	Dent	Orange

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compared by joint analysis of experiments TC 1 and TC 2 in each location, ascertaining the interaction among common lines and the testers.

Results and Discussion

The preliminary analysis of variance, combined over experiments (data not shown), revealed differences ($P < 0.01$) between locations, top crosses and top crosses x locations for all traits, indicating results that should be interpreted for each experiment representing different environments. Thus the analyses of the experiments were presented separately, by location.

The joint analysis of variance associated to the diallel for experiments 1 and 2 (TC 1 and TC 2) in Campinas and Mococa showed significant differences ($P < 0.01$) for testers (T) and lines (L) for the traits, except for Ld+Br for lines in Campinas, indicating high genetic variability (Tables 2 and 3).

The line effect reflected the mean performance of the lines in top crosses with both testers and their capacity to produce superior three-way hybrids. Highly significant differences were detected ($P < 0.01$) for crosses for the 4 variables in Mococa, but only for EH and GY in Campinas that confirmed the genetic variability among the three-way hybrids.

In Campinas there was a significant effect ($P < 0.05$) of the tester x line interaction (TxL) only for EH, but in Mococa the effect of this interaction was highly significant ($P < 0.01$) for PH, EH and GY, indicating an inversion in the discrimination of some lines by the testers. The significance of the interaction shows the presence of genetic dominance (SCA) and/or of epistasis effects involving dominance, in the control of AE.

By partitioning the effects of lines within the testers, it could be detected that both testers were efficient in line discrimination. The significant line (L) effects ($P < 0.01$) indicated the presence of additive effects in the control of all the traits, except for Ld+Br, although effects of dominance and epistasis might also be present.

The mean performance values of the three-way hybrids considering the lines in top crosses with both testers are in the Tables 4 and 5. The three-way cross hybrids yielded differently at tested locations, indicating genetic differences in the behavior among them.

These results agree with Gama *et al*. (1995; 2003), who found that single crosses with a narrow genetic base have a greater environmental interaction than germplasms from a broad genetic base.

The mean yields of the top crosses in Campinas indicated outstanding lines: IP 330, AL 326, L 111, L 10, L 156, L 14, L 4, AL 11 and AL 628 with yields of 8.04, 7.96, 7.87, 7.74, 7.69, 7.62, 7.50, 7.54 and 7.50 t ha^{-1}, respectively. These top crosses were on average 7.7% more productive than the experimental mean (7.17 t ha-1). The percentages of lodged and broken plants ranged from 0.23 to 5.19% for these hybrids, with mean of 1.93%, and were well below the experimental mean, that was 7.1% (Table 4).

The mean yields of the top crosses in Mococa (Table 5) was 8.56 t ha^{-1} and the outstanding lines were L 10, IP 4035, SLP 103, L 126, L 111, L 156, AL 628 and IP 330, yielding in the top crosses 9.46, 9.41, 9.23, 9.40, 9.18, 9.12, 8.92 and 8.92 t ha^{-1}, respectively. These top crosses were on average 7.5% more productive than the mean of the experiments (8.56 t ha^{-1}).

The coefficients of variation (VC%) were considered relatively low, except for (Ld+Br), indicating high experimental accuracy. Lodging occurred inconsistently among the plots and was aggravated by soil preparation programs and *Diabrotica* sp. in Mococa.

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TABLE 2. Mean squares of the joint analysis of variance associated to the general combining ability (GCA) effects of: plant height (PH), ear height (EH), percentage of lodged and broken plants (Ld+Br) transformed in vx + 0,5 and grain yield corrected to 14.0% moisture (GY), of 30 maize lines in top crosses. Campinas, SP, Brazil, 2001/2002.

FV	G.L.	Mean Squares			
		PH (cm)	EH (cm)	Ld+Br (%)	GY ($t\ ha^{-1}$)
Testers (T)	1	7618.01 **	14080.36 **	2741.39 **	14.44 **
Blocks /T	4	517.36	101.19	3.22	0.44 **
Lines (L)	29	910.61 **	609.29 **	80.12	1.57**
T x L	29	486.64	154.34 *	34.71	0.56
Error	116	432.79	100.72	44.98	0.52
Lines/T_1	29	1034.45 **	362.22 **	41.61 **	1.17**
Lines/T_2	29	362.79	401.42 **	4.09	0.96**
Lines / (T)	58	698.63 **	381.82 **	22.85	1.06 **
Crosses	59	494.19	616.52 **	31.75	1.29**
GCA (T)	1	7618.39 **	14098.03 **	2741.61 **	14.4**
GCA (L)	29	910.09 *	611.52 **	80.37	1.57**
V.C.(%)		8.6	7.3	43.9	10.1

*; **: Significant at 5% and 1%, respectively, by the F test.

TABLE 3. Mean squares of the joint analysis of variance associated to the effects of general combining ability (GCA) of the traits: plant height (PH), ear height (EH), percentage of lodged and broken plants (Ld+Br) transformed in vx + 0,5 and grain yield corrected to 14.0% moisture (GY), of 30 maize lines in top crosses. Mococa, SP, Brazil, 2001/2002.

FV	G.L.	Mean Squares			
		PH (cm)	EH (cm)	Ld+Br (%)	GY ($t\ ha^{-1}$)
Testers (T)	1	15106.67 **	10842.27 **	10410.03 **	9.88 **
Blocks/T	4	13.12	34.39	472.19 **	0.66 **
Lines (L)	29	798.97 **	700.55 **	615.99 **	1.63 **
T x L	29	209.85 **	228.99 **	181.52	1.82**
Error	116	78.18	119.38	98.69	0.54
Lines/T_1	29	505.09 **	291.31 **	825.41 **	1.93**
Lines/T_2	29	503.73 **	638.23 **	211.95 **	1.52**
Lines / (T)	58	504.41 **	464.77 **	518.68 **	1.72 **
Crosses	59	749.95 **	638.89 **	739.13 **	1.86**
GCA (T)	1	14960.79 **	10811.20 **	11545.46 **	9.85**
GCA (L)	29	801.78 **	697.74 **	615.84 **	1.63 **
V.C.(%)		3.6	7.8	30.8	8.6

*; **: Significant at 5% and 1%, respectively, by the F test.

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TABLE 4. Mean values of 30 maize lines in crosses with the two testers (single cross hybrids IAC 21 and IA 101.121), for plant height (PH), ear height (EH), percentage of lodged and broken plants (Ld+Br) and grain yield corrected to 14.0% moisture (GY). Campinas, SP, Brazil, 2001/2002.

Lines in Top crosses	PH (cm)	EH (cm)	Ld+Br (%)	GY (t ha^{-1})
L 3 x T	235 ab	134 b-e	1,02 a	7.09 a-e
L 4 x T	246 ab	137 b-e	1,46 a	7.50 a-e
L 5 x T	250 ab	141 b-e	0,12 a	6.81 a-e
L 6 x T	242 ab	139 b-e	3,47 a	6.81 a-e
L 8 x T	232 ab	128 c-e	1,32 a	6.12 de
L 9 x T	227 ab	129 c-e	4,92 a	6.99 a-e
L 10 x T	225 ab	121 e	0,55 a	7.74 a-c
L 13 x T	230 ab	123 de	1,13 a	6.82 a-e
L 14 x T	249 ab	141 b-e	0,32 a	7.62 a-d
L 15 x T	253 ab	140 b-e	0,76 a	7.22 a-e
L 111 x T	249 ab	135 b-e	5,19 a	7.87 a-c
L 117 x T	245 ab	124 de	0,06 a	7.06 a-e
L 126 x T	244 ab	139 b-e	0,78 a	7.29 a-e
L 130 x T	244 ab	139 b-e	0,11 a	7.40 a-e
L 156 x T	235 ab	124 de	0,17 a	7.69 a-d
L 160 x T	235 ab	133 b-e	1,23 a	7.29 a-e
L 161 x T	244 ab	139 b-e	1,13 a	7.16 a-e
L 162 x T	238 ab	121 e	0,79 a	6.76 a-e
L 168 x T	245 ab	140 b-e	3,33 a	6.41 b-e
L 169 x T	242 ab	136 b-e	2,66 a	6.01 e
L 170 x T	233 ab	125 de	3,89 a	6.32 c-e
L 171 x T	231 ab	134 b-e	3,59 a	7.00 a-e
AL 218 x T	211 b	138 b-e	3,91 a	7.03 a-e
AL 326 x T	257 a	148 a-c	3,88 a	7.96 ab
AL 11 x T	261 a	150 a-c	2,15 a	7.53 a-e
AL 628 x T	266 a	163 a	3,52 a	7.50 a-e
IP 330 x T	254 ab	149 a-c	0,23 a	8.04 a
SLP 103 x T	263 a	154 ab	1,79 a	7.39 a-e
IP 701 x T	255 ab	143 a-d	0,29 a	7.35 a-e
IP 4035 x T	251 ab	147 a-c	3,97 a	7.24 a-e
Means of commercial checks	239.52	136.17	0,354	8.75
Means	242.98	137.01	7.14	7.17
D.m.s (5%)	45.85	22.12	14.78	1.60
V.C. (%)	8.6	7.3	43.9	10.1

T = Testers IAC 21 and IAC 101.121.
Means with different letters in the column differ at 5% by the Tukey test.

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TABLE 5. Mean values of 30 maize lines in crosses with two testers (single cross hybrids IAC 21 and IAC 101.121), for plant height (PH), ear height (EH), percentage of lodged and broken plants (Ld+Br) and grain yield corrected to 14.0% moisture (GY). Mococa, SP, Brazil, 2001/2002.

Lines in Top crosses	PH (cm)	EH (cm)	Ld+Br (%)	GY (t ha^{-1})
L 3 x T	240 c-i	138 c-e	32.35 ab	8.69 a-d
L 4 x T	244 b-h	137 c-e	40.84 ab	8.63 a-d
L 5 x T	245 b-g	144 b-d	11.36 b	8.71 a-d
L 6 x T	246 b-e	147 a-c	26.74 ab	8.84 a-d
L 8 x T	228 e-i	131 c-e	36.99 ab	7.83 b-d
L 9 x T	228 e-i	134 c-e	29.74 ab	8.44 a-d
L 10 x T	226 g-i	123 de	12.51 b	9.46 a
L 13 x T	227 f-i	128 c-e	19.77 ab	8.57 a-d
L 14 x T	245 b-g	142 b-d	29.27 ab	8.30 a-d
L 15 x T	256 a-c	147 a-c	29.99 ab	8.16 a-d
L 111 x T	255 a-c	148 a-c	35.78 ab	9.18 a-c
L 117 x T	241 c-i	129 c-e	12.04 b	8.48 a-d
L 126 x T	243 b-I	146 a-d	20.44 ab	9.40 ab
L 130 x T	237 c-i	138 c-e	25.17 ab	8.19 a-d
L 156 x T	238 c-i	133 c-e	15.97 b	9.13 a-c
L 160 x T	234 d-i	117 e	32.69 ab	8.46 a-d
L 161 x T	240 c-i	138 c-e	30.41 ab	8.12 a-d
L 162 x T	227 e-i	128 c-e	42.02 ab	7.65 cd
L 168 x T	239 c-i	144 a-d	52.38 a	8.36 a-d
L 169 x T	237 c-I	143 b-d	28.11 ab	8.17 a-d
L 170 x T	225 hi	129 c-e	23.20 ab	8.11 a-d
L 171 x T	224 i	139 c-e	33.29 ab	7.26 d
AL 218 x T	248 b-d	141 b-e	24.90 ab	8.32 a-d
AL 326 x T	254 a-c	139 c-e	43.03 ab	8.64 a-d
AL 11 x T	249 b-d	146 a-d	22.45 ab	8.67 a-d
AL 628 x T	260 ab	164 ab	51.66 a	8.92 a-c
IP 330 x T	246 b-f	144 b-d	26.03 ab	8.92 a-c
SLP 103 x T	269 a	168 a	21.20 ab	9.23 a-c
IP 701 x T	255 a-c	149 a-c	23.98 ab	8.58 a-d
IP 4035 x T	252 a-d	148 a-c	35.12 ab	9.41 ab
Means of commercial checks	230.33	128.92	11.54	9.76
Means	241.94	139.99	32.21	8.56
D.m.s (5%)	19.48	24.08	21.89	1.62
V.C. (%)	3.6	7.8	30.8	8.6

T = Testers IAC 21 and IAC 101.121.
Means with different letters in the column differ at 5% by the Tukey test.

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Considering the top crosses analysis (Tables 2 and 3), the GCA effect of the group of testers (T) and lines (L) was highly significant for all the traits, except for (Ld+Br) for lines in Campinas, indicating the importance and superiority of the additive genetic effects on the variability of the traits PH, EH, Ld+Br and GY, although dominance and epistasis effects were also acting. Mean squares of the general combining ability of the tester group and the lines group were superior to the mean squares of the specific combining ability, which was given by the SCA of the (T x L) interaction, indicating the importance and superiority of the additive genetic effects in the variability of the traits PH, EH and Ld+Br.

In Mococa, unlike the results in Campinas, a significant ($P < 0.01$) SCA effect was detected (T x L) for all the traits, except for Ld+Br, indicating that the testers discriminated the lines differentially (Table 3). The fact that the interaction T x L effect was significant for the traits PH, EH and GY is an indication that, besides the additive, dominance and/or epistasis genetic effects were also acting in the expression of these traits. Other authors (Singh & Dhillon, 1984; Machado, 1986; Ferrão *et al*., 1994) studied maize varieties in intervarietal crosses using the incomplete partial diallel design, and observed superior values of GCA mean squares compared to SCA for grain weight, in way similar to experiments TC 1 and TC 2.

The estimates of GCA, in experiments TC 1 and TC 2, for the traits PH, EH, Ld+Br, and GY (Table 6) indicated that the lines L 10, L 156, L 111, AL 326, IP 330, L 4 and L 14 were outstanding with positive and high general combining ability (g_i) values for GY, when crossed with the two testers.

Some lines were identified as promising within the breeding program for combining ability that could be used in crosses and to obtain synthetics. The lines L 10 and L 156 were outstanding and contributed to reduction in lodging and breaking. Lines IP 330, L 4 and L 14 contributed to reducing the lodging rates. Other lines were outstanding because they had unfavorable alleles – L 168, L 169, L 170 and L 6 contributing negatively to yield and favored increased lodging rates (Table 6).

Moreto *et al*. (2002) assessed hybrids of inbred maize lines and detected significant GCA and SCA effects for the variables PH, EH, GY, indicating that more productive lines can be selected within the groups and thus more productive hybrids can be obtained. Ribeiro *et al*. (2002) assessed maize population performance in diallel crosses and obtained more pronounced additive effects for the variables PH, EH and GY, although the interaction effects were also significant. Other authors utilized top crosses and diallels and concluded that top crosses are more efficient to lines discrimination (Baktash *et al*.,1981).

The GCA estimates for the traits PH, EH, Ld+Br and GY for the lines under study are in Table 6. Lines L 10, L 126, SLP 103, IP 4035, L 111, AL 628 and IP 330 all presented positive and high GCA effects for GY, when crossed with the testers.

Lines L 10, L 156, L 126 and SLP 103 were outstanding for combining ability and could be used in crosses and to obtain synthetics. Lines L 10 and L 156 were outstanding because they had favorable alleles for plant and ear height and lodging reduction, while lines L 126 and SLP 103 reduced lodging and had favorable alleles for increasing grain yield (Table 6).

Lines L 8, L 14, L15, L 130, L 161, L 162, L 169 and L 170 showed lower and negative values of GCA, because they possessed unfavorable alleles that would contribute to

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TABLE 6. Estimates of the general combining ability of 30 maize lines for the traits: plant height (PH), ear height (EH), percentage of lodged and broken plants (Ld+Br) and grain yield corrected to 14.0% moisture (GY).Campinas and Mococa, SP, Brazil, 2001/2002.

Lines	General combining ability (g_i)							
	PH (cm)		EH (cm)		Ld+Br (%)		GY (t ha^{-1})	
	Campinas	Mococa	Campinas	Mococa	Campinas	Mococa	Campinas	Mococa
L 3	-9.68	-1.48	-3.55	-1.52	-0.50	3.42	-0.074	0.133
L 4	1.82	2.02	0.45	-3.02	-0.53	12.61	0.337	0.072
L 5	5.82	3.52	3.95	3.98	-2.29	-18.03	-0.361	0.147
L 6	-2.58	4.52	1.95	6.98	1.65	-2.64	-0.357	0.278
L 8	-12.68	-13.48	-8.55	-9.02	-0.75	6.69	-1.052	-0.728
L 9	-17.68	-13.98	-8.05	-6.02	2.93	0.38	-0.178	-0.123
L 10	-20.18	-15.48	-16.55	-17.52	-1.43	-16.75	0.574	0.903
L 13	-14.68	-15.48	-14.05	-11.52	-1.38	-9.44	-0.344	0.011
L 14	4.81	3.52	3.45	1.48	-2.19	1.41	0.454	-0.274
L 15	8.32	14.02	2.45	6.98	-1.02	1.94	0.049	-0.396
L 111	4.32	13.52	-2.55	7.48	3.82	6.50	0.704	0.619
L 117	0.32	-1.48	-13.05	-11.52	-2.40	-17.37	-0.110	-0.077
L 126	-0.68	1.02	1.95	5.48	-1.68	-8.81	0.124	0.834
L 130	-0.68	-5.48	1.95	-2.02	-2.29	-3.26	0.231	-0.372
L 156	-9.68	-4.48	-13.05	-7.02	-2.18	-13.19	0.526	0.565
L 160	-9.18	-8.48	-3.55	-23.02	-0.09	3.30	0.125	-0.105
L 161	-1.18	-1.98	1.45	-2.02	-1.05	3.82	-0.00967	-0.443
L 162	-6.68	-14.48	-15.55	-12.52	-1.59	12.68	-0.412	-0.912
L 168	-0.18	-2.98	2.45	3.98	2.53	22.73	-0.756	-0.205
L 169	-3.18	-4.98	-1.05	3.48	0.24	-0.96	-1.152	-0.392
L 170	-11.68	-17.48	-12.05	-11.02	2.03	-6.21	-0.846	-0.448
L 171	-13.18	-17.98	-3.55	-1.52	2.97	4.56	-0.172	-1.297
AL 218	15.82	6.02	0.45	0.98	2.63	-2.73	-0.138	-0.244
AL 326	11.82	12.02	10.95	-1.02	1.64	13.66	0.791	0.082
AL 11	16.32	7.02	12.95	5.98	0.22	-6.94	0.367	0.112
AL 628	21.32	18.52	25.95	23.98	2.85	22.09	0.329	0.363
IP 330	8.82	4.02	11.45	3.98	-2.07	-3.35	0.867	0.363
SLP 103	17.82	27.02	16.95	27.98	-0.03	-6.97	0.225	0.666
IP 701	10.32	12.52	6.45	8.98	-1.95	-4.94	0.178	0.019
IP 4035	6.32	10.52	9.95	8.48	1.86	5.85	0.076	0.847
Error (gi)	8.35	3.55	4.03	4.39	2.69	3.99	0.290	0.295
Error (gj-gj')	12.01	5.10	5.79	6.31	3.87	5.74	0.418	0.424

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weight reduction. Lines L 8, L 14, L 161 and L 162, in addition to contributing negatively to yield, have alleles that favor increased lodging rates. These lines should be eliminated of the program or used with other testers because, with these, the results were bad. However it can be that with other testers these results could be different.

Conclusions

Both the testers were efficient in discriminating lines and enabled superior triple hybrids to be obtained.

A significant number of triple hybrids presented yield similar to the commercial hybrids used as checks. The following triple hybrids were outstanding: IAC 21 x IP 330, IAC 21 x L 156, (IAC 101.121) x L 10 and (IAC 101.121) x SLP 103 for high yield and low lodging and breaking rates.

The fact that the interaction Testers x Line effect was highly significant for plant and ear height, and grain yield is an indication that, besides the additive genetic effects, genetic effects of dominance and/or epistasis were also acting in the expression of these traits.

Lines L 10, L 156, L 126, L 111, SLP 103 and IP 330 were outstanding for general combining ability, with positive and high combining ability effects for grain yield, which should be useful to maize breeding programs.

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