EVALUATION OF MAIZE (Zea mays L.) TOP CROSSES FOR THEIR POTENTIAL USE IN A BREEDING PROGRAM[1]

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ABSTRACT – A 15 x 5 partiall diallel including parents were evaluated at three locations, (Sete Lagoas, MG, Goiânia, GO and Londrina, PR in Brazil. Significant differences (P < 0.01) for locations, entries, heterosis, average heterosis, heterosis in crosses and locations x entries were detected in the combined analysis of variance. Average heterosis was 643 kg/ha (8.40%) for the top crosses. The largest SC effect (Set 1) was for SC 3 (628 kg/ha) and the smallest for SC 1 (-1106 kg/ha); the greater variety heterosis mean effect was for SC 15 (684 kg/ha) and the lower for SC 11 (-810 kg/ha). In Set 2 the largest population effect was for CMS 06 (981 kg/ha) and the smallest for CMS 05 (-911 kg/ha). CMS 05 had the largest heterosis effect (471 kg/ha), while CMS 12 (-451 kg/ha) had the smallest. The largest specific heterosis effect was for the top cross SC 6 x CMS 06 (797 kg/ha). In general, SC and populations had more environmental interaction than top crosses.

Index terms: diallel, single cross hybrids, plant populations, interaction.

AVALIAÇÃO DE "TOP CROSSES" QUANTO AO SEU POSSÍVEL USO EM PROGRAMAS DE MELHORAMENTO DO MILHO

RESUMO – Foram avaliados 75 cruzamentos num dialélico parcial 15 (híbridos simples, conjunto 1) x 5 (populações, conjunto 2) juntamente com os parentais, em 3 localidades [Sete Lagoas (MG), Goiânia (GO) e Londrina (PR)], no Brasil. Foram encontradas diferenças significativas (P<0,01) para locais, tratamentos, heterose, heterose média, heterose nos cruzamentos e para a interação tratamentos x locais. Os "top crosses" apresentaram heterose média de 643 kg/ha (8,40%). O maior efeito de híbrido simples (SC) foi para SC-3 (628 kg/ha), e o menor, para SC-1 (-1106 kg/ha); o maior efeito heterótico foi para SC-15 (684 kg/ha), e o menor, para SC-11 (-810 kg/ha). Para as populações, o maior efeito de população foi para CMS-06 (981 kg/ha), e o menor, para CMS-05 (-911 kg/ha). A população CMS-05 apresentou o maior efeito de heterose (471 kg/ha), enquanto que a população CMS-12 apresentou o menor (-451 kg/ha). A maior heterose específica (797 kg/ha) foi estimada para o cruzamento entre o híbrido simples SC-6 e a população CMS-06. De modo geral, os híbridos simples e as populações apresentaram maior interação com os ambientes que os "top crosses".

Termos para indexação: dialelo, híbridos simples, populações de plantas, interação.

INTRODUCTION

The use of maize inbred lines to produce double-cross hybrids was suggested by Jones (1918). Excellent hybrids were developed for farmers with an increase in the levels of productivity (Duvick 1984). Hybrid breeding programs require breeders to make decisions on the choice of appropriate selected lines or base populations for inbred line development. The proper choice and use of testers is closely related to the objectives of the breeding program (Davis 1927).

Genetic variability among testcrosses depends on differences in allele frequency between tester and lines crossed to tester and level of dominance. Lopez-Perez (1979) found that variability among testcrosses of an unrelated high yielding tester was similar to the genetic variance with a related

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low yielding tester. The use of such a tester is suggested to select lines having high general and specific combining ability and as a source for population improvement (Lopez-Peres 1979).

In hybrid development programs, it is common to use inbred lines as testers to obtain high yielding single-cross hybrids (Russell 1961). However, the use of single crosses as testers is considered to be a rapid method to identify the best three-way and double cross combinations for commercial hybrid development. Information concerning yield responses of high yielding single crosses in cross with broad-base populations is valuable to maize breeders in planning future selection programs aimed at hybrid production.

The objective of this study was to determine the genetic effects of narrow-base testers on the evaluation of populations as sources of inbred lines for hybrid development and population improvement.

MATERIALS AND METHODS

In 1986, at the Centro Nacional de Pesquisa de Milho e Sorgo (CNPMS), Sete Lagoas, MG, Brazil, 200 S_2 maize lines derived from population CMS 11 (CIMMYT's Pool 21) were topcrossed using as tester a bulk of seeds of S_2 lines of population CMS 28 (CIMMYT's Tuxpeño 1 Amarillo). The same procedure was used to obtain 200 topcrosses of S_2 lines from CMS 28 crossed to a bulk of S_2 lines of CMS 11. These 400 S_2 lines were advanced in the same year by selfing to the S_3 generation. The 400 top crosses were evaluated in three environments, in 1987, and the best 10 S_3 lines selected from each population. A partial diallel set of crosses among the 20 S_3 lines was produced in the Winter of 1988. In 1988/89 100 single crosses were evaluated in three environments and the 15 best yielding single crosses were selected.

The 15 single crosses plus CMS-05 (Suwan DMR), CMS 06 [(BR 126 + Maya + Centralmex) x (Tuxpeño Amarillo 1)], CMS 12 (CIMMYT's Pool 22), CMS 14 (CIMMYT's Pool 25), and CMS 50 (a 32 lines synthetic variety developed at CNPMS) were intercrossed in a 15 x 5 partial diallel to form 75 top crosses. Seeds of theses crosses and parents were produced in the same year using a minimun of 50 plants in sib crosses and top crosses in 1989. The experiment included 75 top crosses, 15 single crosses (Set 1), five populations (Set 2), and five commercial double-cross hybrids. Trials were conducted in three environments in 1989, Sete Lagoas, MG (latitude 19° 28'S, longitude 44° 15' W), Goiânia, GO (latitude 16° 41'S, longitude 49° 16'W) and Londrina, PR (latitude 23° 19' S, longitude 51° 19' W). The experimental design was a 10 x 10 simple lattice with two replications per environment. Plot size was two-rows 5.00 m long with 25 plants per row with a plant density to 50,000 plants per hectare. Data were taken for ear weight adjusted to 15.5% moisture. Analysis of the partial diallel crosses repeated across environments was computed according to Oliveira et al. (1987). For each environment the analysis of variance were computed on yield data, and the adjusted entry means and effective error mean squares were used to perform the combined analysis across locations (Cochran & Cox 1957).

RESULTS AND DISCUSSION

The mean squares for ear weight with the partitioning of the total sum of squares according to Gardner & Eberhart's (1966) model adapted to partial diallels and the interaction of sources of variation with locations are shown in Table 1 for the 15 x 5 partial diallel crosses. The variation among single cross and parental population was highly significant ($P < 0.01$). These differences were expected due to the heterogeneity of the material included in this study. Average heterosis (8.40%) was highly significant. Heterosis in crosses of both sets was significantly different ($P < 0.05$), meaning that single crosses contributed differently to the crosses with the populations. A nonsignificant variation for specific heterosis among crosses was detected, meaning that general combining effects were more important. The locations x entries interaction was highly significant, indicating that the different entries reacted differently to environments. Locations x Populations was significant but Locations x Single crosses was not significant because stability of genotypes across environments has, in most instances, been related to the heterogeneity of the material under test (Sprague & Federer 1951, Eberhart et al. 1964, Eberhart & Russell 1969). Heterosis in crosses of single crosses interacted significantly with environments.

TABLE 1. Combined analysis of variance for ear weight (kg/ha) in three locations for the 15 x 5 partial diallel with 15 single cross (Set 1) and five population (Set 2) parents. Sete Lagoas-MG, Londrina-PR and Goiânia-GO, 1989/90.

Source	d.f.	Mean squares
Locations (L)	2	172410702**
Entries	94	1514295**
Single crosses (Set 1)	14	2204043**
Populations (Set 2)	4	9526361**
Sets	1	4526361**
Heterosis	75	917362**
Average	1	15525751**
Single crosses	14	1087181**
Populations	4	1456015*
Specific	56	575569
L x Entries	188	561279**
L x Single crosses (Set 1)	28	669132
L x Populations (Set 2)	8	954033*
L x Sets	2	898154
L x Heterosis	150	515730
L x Average	2	1017650
L x Single crosses (Set 1)	28	745352
L x Populations (Set 2)	8	640792
L x Specific	112	440429
Residue	243	492603

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

Data for mean ear weight of single crosses and populations per se, effect of each parent (p), specific heterosis effects (in parentheses), single cross and population heterosis effects (h), average heterosis (h), and single cross and population means in crosses, parent means, and the general mean are shown in Table 2. The single cross parents per se (Set 1) averaged 14.6 % more yield than populations per se (Set 2). The best yielding single crosses were SC5 and SC3, which involved four different lines. SC5 and SC3 had 12.4% and 11.3% higher yield than the best population (CMS 06), in Set 2, respectively. Positive effects of heterosis in crosses occurred for 8 of 15 single crosses (Set 1) with SC15 having the highest value.

For populations (Set 2), positive effects of heterosis in crosses occurred for CMS 05 and CMS 50. It should be noted, however, that heterosis of single cross and populations in crosses in most instances was not related to its *per se* performance. Heterosis depends on heterozygous loci (Vencovsky 1980). Thus, an explanation would be that lower yielding genotypes had fewer heterozygous loci, or more inbreeding, and, consequently, greater diversity with other genotypes. The highest specific heterosis effects were for crosses SC6 x CMS 06 (797 kg/ha), SC5 x CMS 50 (612 kg/ha), and SC8 x CMS 05 (606 kg/ha). The highest yielding topcross also had the highest but non significant specific heterosis effect (797); heterosis was 22,1 % for parent means and 8.2 % in relation to the highest yielding parent.

Single cross and population Treatments x Location interaction effects and Heterosis x locations effects are shown in Table 3. The interaction is helpful in choosing the best location to work with a specific population in a breeding program or a single cross to produce hybrid seed. The highest positive interaction values were obtained for population CMS 06 when evaluated in Goiânia, followed by CMS 05 at Sete Lagoas and Londrina. The highest yielding single crosses SC5 and SC3 had high performance at Goiânia and Sete Lagoas, respectively. In relation to heterosis x locations effects, the estimated effects for populations CMS 14 and CMS 50 showed a similar interaction pattern with positive heterosis in crosses at Sete Lagoas and Goiânia. This type of information is important in the case of line development for either specific or broad areas of adaptation while trying to maximize heterosis.

The seed industry in Brazil commonly uses single crosses of maize with flint endosperm as male parent, and single crosses with dent endosperm as female parent, to produce double cross hybrids of intermediate endosperm type. In a program for hybrid development, it is important to identify narrow genetic-base testers (lines or single crosses) to be used in the identification of lines with good potential to be included as parents in hybrids for commercial hybrid development.

The first step towards hybrid development was the selection of the best single cross with

TABLE 2. **Mean ear weight (kg/ha) of populations and single crosses heterosis effect (h), *per se* mean effect of each parent (p) and specific heterosis effect (in parentheses), in a 15 x 5 partial diallel for five populations (set 2) and 15 single crosses (set 1). Sete Lagoas-MG, Londrina-PR and Goiânia-GO, 1989/90.**

Parents / Set 1	Set 2 CMS 05	CMS 06	CMS 12	CMS 14	CMS 50	Mean	(ĥ)	Single cross Set 1 per se	(p̂)
SC1	7826	7586	6438	7713	8192				
	(259)	(-447)	(-395)	(204)	(379)	7551	438	6468	-1106
SC2	8571	8889	7672	8137	8377				
	(226)	(77)	(60)	(-148)	(-215)	8329	357	8187	612
SC3	8264	8623	7043	7551	8129				
	(326)	(129)	(-162)	(-329)	(-54)	7922	-158	8403	628
SC4	8585	8393	7643	7508	8917				
	(346)	(-302)	(147)	(-662)	(472)	8213	200	8268	694
SC5	7751	7111	6697	7738	8417				
	(193)	(-914)	(-128)	(237)	(612)	7543	-589	8507	933
SC6	7163	8915	6998	7830	7269				
	(-487)	(797)	(80)	(238)	(-628)	7635	-118	7748	173
SC7	7558	7418	7604	7911	8124				
	(-180)	(-788)	(598)	(231)	(139)	7723	-176	8041	466
SC8	7736	8021	5837	6939	6742				
	(606)	(484)	(-499)	(-71)	(-575)	7054	-171	6693	-881
SC9	7909	8453	6888	7929	7408				
	(179)	(239)	(-108)	(258)	(-568)	7714	34	7601	27
SC10	7453	7805	6488	7720	8059				
	(-67)	(-183)	(-300)	(258)	(292)	7505	-297	7846	272
SC11	6770	7430	6450	7157	7770				
	(-360)	(-167)	(51)	(84)	(392)	7115	-810	8092	518
SC12	7481	8499	6882	7714	7620				
	(-173)	(377)	(-39)	(117)	(-281)	7639	505	6510	-1064
SC13	7683	7976	4295	6669	7782				
	(186)	(12)	(531)	(-769)	(39)	7481	22	7160	-414
SC14	6994	8646	7062	8228	7600				
	(-727)	(457)	(73)	(564)	(-368)	7706	80	7492	-82
SC15	7491	8484	7236	7610	8490				
	(-386)	(138)	(91)	(-208)	(365)	7862	684	6598	-976
Mean	7682	8249	6949	7624	7928	7666		7575	
(h)	471	-8	-451	-313	302				
Population Set 2 per se	5559	7453	5138	7013	6392	6311		7589*	
(p)	-911	981	-532	541	-79				

Average heterosis (ĥ) = 643 (8.40%)

* General Mean

TABLE 3. Treatment x location effects and heterosis x location effects (in parentheses) for the 15 x 5 partial diallel of 15 single crosses and five populations. 1989/1990.

Treatments	Locations		
	Londrina-PR	Goiânia-GO	Sete Lagoas-MG
SC1	309	-731	422
	(-241)	(164)	(-222)
SC2	384	-346	-38
	(-324)	(677)	(-354)
SC3	72	-509	437
	(-454)	(439)	(15)
SC4	-1072	828	244
	(739)	(-196)	(-543)
SC5	228	869	-1097
	(606)	(-938)	(332)
SC6	-703	4	699
	(534)	(-253)	(-281)
SC7	875	-506	-369
	(-1038)	(124)	(914)
SC8	310	-759	449
	(-34)	(44)	(-10)
SC9	313	-1739	1426
	(-636)	(955)	(-319)
SC10	74	-5	-69
	(-135)	(81)	(53)
SC11	607	165	-772
	(-299)	(-174)	(474)
SC12	18	50	32
	(12)	(27)	(74)
SC13	-63	954	-891
	(-59)	(-146)	(239)
SC14	-674	424	250
	(443)	(-42)	(-402)
SC15	-441	598	-158
	(226)	(-408)	(181)
CMS 05	156	-582	425
	(53)	(352)	(-405)
CMS 06	-465	1108	-643
	(645)	(-714)	(69)
CMS 12	36	-78	42
	(23)	(24)	(-47)
CMS 14	372	-425	52
	(-377)	(138)	(239)
CMS 50	-100	-25	124
	(-344)	(199)	(144)

intermediate endosperm kernel. The best yielding single crosses were identified, but how would these single crosses perform in crosses with different materials? Could we choose any one of them to be used as a tester for double hybrid production? Our results showed that single crosses produced by crossing lines derived from the same two populations did not test similarly for combining ability, as shown by the different ranking of the populations. Similar results were found by Keller (1949). (Table 4).

According to the mean yield and the heterosis effects found in this study, inferences can be made to the use of a specific single cross as a tester to select high yielding inbred lines. Close agreement can be found in the results obtained by Horner et al. (1976). Single crosses SC4, SC14, SC6 and SC7 would be the best testers to be used in selecting inbred lines from the populations CMS 50 and CMS 05, CMS 14, CMS 06 and CMS 12, respectively. The single crosses could also be used as testers in a population improvement program,

TABELA 4. Identification and yield of the 15 single crosses utilized in this study.

	Inbred (CMS 11)	Inbred (CMS 28)	Yield
01 - SC 1	L269	L284	6468
02 - SC 2	L269	L282	8187
03 - SC 3	L269	L53	8403
04 - SC 4	L269	L280	8268
05 - SC 5	L270	L282	8507
06 - SC 6	L270	L53	7748
07 - SC 7	L270	L275	8041
08 - SC 8	L274	L284	6693
09 - SC 9	L274	L280	7601
10 - SC 10	L274	L282	7846
11 - SC 11	L274	L53	8092
12 - SC 12	L266	L53	6510
13 - SC 13	L266	L280	7160
14 - SC 14	L266	L282	7492
15 - SC 15	L20	L16	6598

either for general or specific combining ability (Horner et al. 1973 and 1976, Penny 1959, Lonnquist 1961).

Based on interaction effects of single crosses and populations *per se* for seed production, the highest yielding crosses SC2 x CMS 05 would be produced at Londrina, SC 6 x CMS 06 at Goiânia, and SC 4 x CMS 12, SC 14 x CMS 14, and SC 4 x CMS 50 at Sete Lagoas. For line development in either a specific or a broad area of adaptation, the heterosis x locations effects indicated the SC 8 and CMS 05 should give high heterotic hybrids at Goiânia since both parents had positive interactions. Similarly, SC 6 x CMS 06, SC 7 x CMS 12, SC 9 x CMS 14 and SC 5 x CMS 50 would have best results at Londrina, Goiânia, and Sete Lagoas, respectively.

CONCLUSIONS

1. Both single cross hybrides and populations showed differences in yield ability *per se* and in crosses.
2. Single cross hybrids averaged 14,6% more yield than populations.
3. The SC5 and SC3 single cross hybrids and populations CMS 06 and CMS 14 were the highest yielding *per se*.
4. Top crosses showed a mean heterosis of 643 kg/ha (8,4%).
5. SC 15 and SC 12, and CMS 05 and CMS 50 in each set had the greatest heterotic effects.
6. The highest yielding top crosses SC 4 x CMS 50 (8917 kg/ha) and SC 6 x CMS 06 (8915 kg/ha) showed also high positive values for specific heterosis (425 kg/ha and 789 kg/ha, respectively).
7. It was possible to identify and to select the best tester for each population, in each environment, to be used in a breeding program.

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