Rev. Brasil. Genet. 17, 3, 277-282 (1994)
(Brazil. J. Genetics)

DIALLEL AMONG TWENTY EIGHT VARIETIES OF MAIZE

M.X. dos Santos, C.A.P. Pacheco, P.E.O. Guimarães, E.E.G. e Gama, A.E. da Silva and A.C. de Oliveira

ABSTRACT

Twenty eight varieties of maize of different maturities and types of endosperm were assessed together with 378 F_1, and seven commercial hybrids (controls) in three locations: Sete Lagoas, MG, Goiânia, GO, and Londrina, PR. The varieties represent germplasms adapted to different areas of Brazil, used in the breeding program at the National Maize and Sorghum Research Center at Sete Lagoas, MG. The joint analysis of variance for ear weight showed significance ($P < 0.01$) for environments, entries, varieties, heterosis, mean heterosis, variety heterosis, specific heterosis, environments x entries and environments x varieties. The average yield of the varieties varied from 2,322 to 7,704 kg/ha, while for the intervarietal hybrids the variation was from 4,112 to 8,363 kg/ha. The mean heterosis was 489 kg/ha and the varietal heterosis varied from -589 to 1,339 kg/ha. The highest specific heterosis was obtained for the BR 105 x BA III - Tusón crossing. Some intervarietal hybrids were higher yielding than the best control. This is promising for breeding purposes, since new synthetic varieties can be formed or used to begin programs to produce hybrids. No association was found between heterosis and endosperm type.

INTRODUCTION

Developing high yielding maize populations with desirable agricultural characteristics is an important step for a successful breeding program which can meet the market demands of third world countries. From these populations superior inbred lines are likely to be obtained since the frequency of favorable alleles is increased by interpopulational breeding (Paterniani and Miranda Filho, 1987).

The National Center for Maize and Sorghum Research (CNPMS) has dedicated most of its work to produce improved maize populations because of their fundamental importance. However, since intervarietal heterosis can be of immediate use in specific hybrid combinations, an assessment of these populations' performance in crossings was made. Diallel crossings (Gardner and Eberhart, 1966) have been widely used for the identification of population performance and of heterotic expression in crossings. Various studies have been done with this method, showing its usefulness in the breeding programs (Hallauer, 1972; Naspolini *et al.*, 1981; Souza Jr., 1981; Gama *et al.*, 1984).

Morais *et al.* (1991) developed a simplified method to analyse the experimental results obtained from the model proposed by Gardner and Eberhart (1966). It allows the assessment of experiments carried out in several environments, taking into account the interaction of the estimated effects and the locations.

The objective of this study was to evaluate the genetic potential of 28 maize populations *per se* and in crossings.

MATERIAL AND METHODS

Twenty eight varieties of maize from the CNPMS-EMBRAPA breeding program and adapted to nearly all growing areas of the country were used. Most of these populations had already been submitted to several cycles of selection and some are recommended for cultivation in different regions of Brazil. Their identification and characteristics are shown in Table I.

Crossings were carried out in the winter seasons of 1990 and 1991 in Sete Lagoas, MG, using five m^2 paired rows. At least 60 crosses were obtained. Each parent was also planted in four-row plots, the first two rows being used for sib mating and the remaining two rows for self pollina-

Centro Nacional de Pesquisa de Milho e Sorgo, EMBRAPA/CNPMS, Caixa Postal 151, 35701-970 Sete Lagoas, MG, Brasil. Send correspondence to M.X.S.

Table I - Some characteristics of 28 tropical lowland maize varieties.

Variety	Characteristic			
Mezcla Amarillo (CMS 1)	CS1	Y	SF	IM
Antigua x Vera Cruz (CMS 2)	CS1	Y	SD	IM
Amarillo Cristalino (CMS 3)	CS1	Y	F	IM
Amarillo Dentado N (CMS 4N)	CS9	Y	D	IM
Amarillo Dentado C (CMS 4C)	CS6	Y	D	IM
Suwan DMR (BR 105)	CS9	O	F	IM
BR 106	CS9	Y	SD	IM
BR 107	CS8	O	F	IM
BR 111 (Pool 21)	CS5	Y	F	IM
BR 112 (Pool 22)	CS5	Y	SD	IM
Pool 25 (CMS 14C)	CS5	Y	SF	IM
Pool 26 (CMS 15)	CS1	Y	D	LM
Amarillo del Bajio (CMS 22)	CS8	Y	SD	IM
Ant. x Rep. Dominicana (CMS 23)	CS1	Y	D	EM
BR 126	CS11	Y	D	LM
MS 28	CS6	Y	SD	IM
Amar. del Bajio x Templados (CMS 29)	CS1	Y	SF	IM
Composto Amplo (CMS 30)	CS8	Y	SD	LM
BR 136	CS6	Y	SF	LM
CMS 39	CS5	Y	D	LM
CMS 50	CS2	Y	SD	IM
Sint. Elite	CS1	Y	SD	IM
Ph 4	CS1	Y	F	EM
Cunha	G	Y	D	LM
BA III - Tusón	G	Y	D	LM
Saracura	GS3	Y	F	IM
Nitroflint	CS4	Y	F	LM
Nitrodent	CS4	Y	D	LM

O = Orange kernel; Y = Yellow kernel; D = Dent; SD - Semi-Dent; F = Flint; SF = Semi-Flint; LM - Late maturity; IM = Intermediate maturity; EM = Early maturity; CS = Cycles of selection; G = Material from germplasm bank.

tion. In both winter generations a minimum of 70 sibs and 70 self pollinated plants (S_1) were obtained for each parent.

In the 1991/92 season the 378 intervarietal crosses and 28 parents were assessed in a 21 x 21 lattice with two replications, seven commercial hybrids (controls) and the 28 S_1 varieties completing the 441 entries. The controls were G 85, BR 201, BR 205, XL 560, AG 303, P 3072 and C 506. The experimental plots were made up of two five meter rows spaced 1.0 m apart and 0.20 m between hills, with one plant per hill after thinning. The trials were carried out in the normal growing period (sowings in October/ November) without supplementary irrigation. The ear-weight of the parents and intervarietal crosses converted to kg/ha was submitted to an analysis of variance for each location.

A combined analysis of variance was carried out with the adjusted treatment means, according to the Gardner and Eberhart model (1966) and according to the modification introduced by Morais *et al.* (1991).

RESULTS AND DISCUSSION

The selection of genotypes suitable for a large number of environments is the main objective of the maize breeder. Table II shows the combined analysis of variance for ear weight in three locations. The main effects of environments, entries, varieties, heterosis, mean heterosis, variety heterosis, specific heterosis and the interaction between environment x entries and environment x varieties were all significant at the 1% level of probability. The coefficient of variation was considered acceptable for the ear weight trait.

Table II - Results of combined analysis of variance for ear weight (kg/ha) for 28 parental varieties of maize and their crosses tested over three environments. Agricultural year, 1991/92.

Source of variation	DF	M.S.	F
Environments	2	339642119.84	586.97**
Entries	405	1743645.50	3.01**
Varieties	27	9627466.72	16.64**
Heterosis	378	1180515.42	2.04**
Mean heterosis	1	18728845.38	32.37**
Variety heterosis	27	1675259.31	2.90**
Specific heterosis	350	1092211.38	1.89**
Environments x Entries	810	740574.92	1.28**
Environments x Varieties	54	2205027.96	3.81**
Environments x Heterosis	756	635971.14	1.10
Environment x Mean heterosis	2	889215.61	1.54
Environment x Varieties heterosis	54	565673.60	0.98
Environment x Specific heterosis	700	641940.84	1.11
Mean pooled error	1200	578634.20	

**Significant at the 1% level.
CV = 17.83%.

The significant differences among environments and significant interactions of environments x entries and environments x varieties had already been detected by Parentoni *et al.* (1990) working with early maturing populations in the same locations. Gama *et al.* (1984) and Lopes *et al.* (1985), working in different locations, also reported the existence of significant interactions between environments and populations. Interactions of the magnitude found in the present work are expected when distinct locations, considering the geographic distance, the climate and the soil, are included in the study. This emphasizes the need to select specific genotypes for a specific ecological region, as has been recommended by private seed companies.

On the other hand, the highly significant differences ($P < 0.01$) found for the entry and variety effects indicated that the analysis was able to discriminate the 28 varieties for their heterotic potential and their productive capacity *per se*. The difference between the best intervarietal hybrid (BR 105 x BA III) and the poorest (CMS 2 x CMS 30) was 4,251 kg/ha. The difference between the most productive variety (BR 106) and the least productive (BA III) was 5,382 kg/ha (Table III).

Table III - Estimates of varietal effects ($\hat{v}_i$), varietal heterosis ($\hat{h}_i$), mean of each variety (kg/ha) and average heterosis ($\bar{h}$), for ear weight combined from three locations in Brazil, Agricultural year 1991/92.

Varieties	$\hat{v}_i$	$\hat{h}_i$	Mean (kg/ha)
01. Mezcla Amarillo (CMS 1)	-346.90	-224.76	5690
02. Antigua x Vera Cruz (CMS 2)	-1379.24	121.74	4655
03. Amarillo Cristalino (CMS 3)	-714.57	-30.41	5318
04. Amarillo Dentado N (CMS 4N)	1092.76	-450.43	7127
05. Amarillo Dentado C (CMS 4C)	1184.43	-589.45	7218
06. Suwan DMR (BR 105)	1297.09	-50.47	7332
07. BR 106	1670.77	-354.66	7704
08. BR 107	-148.91	-167.52	5884
09. BR 111 (Pool 21)	8.09	34.42	6042
10. BR 112 (Pool 22)	122.76	-101.99	6156
11. Pool 25 (CMS 14C)	-566.57	429.68	5467
12. Pool 26 (CMS 15)	283.43	-411.63	6318
13. Amarillo del Bajio (CMS 22)	143.76	-102.31	6178
14. Ant. x Rep. Dominicana (CMS 23)	-668.90	-40.17	5367
15. BR 126	-1196.23	614.33	4837
16. CMS 28	24.09	429.27	6059
17. Ama. del Bajio x Templados (CMS 29)	475.76	-506.78	6510
18. Composto Amplo (CMS 30)	-425.57	79.58	5608
19. BR 136	-356.24	49.76	5679
20. CMS 39	240.76	109.13	6276
21. CMS 50	541.76	-100.66	6575
22. Sint. Elite	365.43	152.29	6400
23. Ph 4	-1300.24	519.35	4733
24. Cunha	-5.57	24.16	6029
25. BA III - Tusón	-3711.57	1339.25	2322
26. Saracura	1530.09	-454.08	7563
27. Nitroflint	459.76	-106.70	6493
28. Nitrodent	1379.76	-210.90	7415
$\bar{h}$		489	
μ			6033

Of the total sum of squares, 37% was due to the variety effects and 63% to the overall heterotic effects. Of the total heterosis, 2.7%, 6.3% and 54% were due to the mean heterosis, variety and specific effects, respectively. The correlation between the sum of squares of variety and total heterosis was very low, showing that the intervarietal dominance effects were far superior to the intravarietal dominance effects. Different results were reported by Gardner and Paterniani (1967), Gama *et al.* (1984) and Parentoni *et al.* (1990) who showed the majority of the variation among populations stemmed from intravarietal dominance effects.

The analysis of the components of the total heterotic effects showed significant mean, varietal and specific heterosis, indicating that there are differences among the heteroses and that these differences are due to varietal and to specific heterosis. Consequently, there must be at least one hybrid whose high mean value is due not only to varietal heterosis but also to the interaction between varieties. Similar results were shown by Hallauer and Sears (1968), Troyer and Hallauer (1968), Hallauer (1972) and Gama *et al.* (1984).

Table III shows the estimates of the variety effects (V_i), variety heterosis (h_i), the variety mean (kg/ha), mean heterosis (h) and general mean of the parents (μ). The variety BA III - Tusón showed the greatest varietal heterosis value and the lowest variety effect value. According to Vencovsky (1970) there are three situations that can explain a high varietal heterosis value: a) varieties that have many loci with dominant alleles; b) varieties that have a greater dispersion in gene frequency in comparison with the average frequencies of the set of populations; c) varieties that have many loci with a low frequency of dominant alleles. Thus this variety is the most genetically divergent in relation to the others. The frequency of favorable genes showing some degree of dominance in this variety is lower than the average frequencies in the other varieties. Similar situations are reported in the literature (Souza Jr., 1981 and Parentoni *et al.*, 1990).

The average of the 378 F_1 hybrids (above the diagonal) and the specific heterosis value (below the diagonal) are shown in Table IV. The best cross produced 8,363 kg/ha and the poorest 4,112 kg/ha. The specific heterosis values showed wide variation. Of the seven controls (commercial hybrids) five produced from 6,379 to 6,594 kg/ha, one produced 7,198 kg/ha and the other two produced over 8,000 kg/ha.

According to Sprague and Tatum (1942), high specific heterosis values (positive or negative) indicate better or worse combinations in relation to the varietal heterosis, while low values indicate that the two parent varieties behave as expected in varietal heterosis effects. The significance ($P < 0.01$) of the specific heterosis values stems from the different F_1 values (Table IV) and shows

Table IV - Means of ear weight in kg/ha (above diagonal) and specific heterosis in kg/ha (below diagonal) for F1 maize intercross varieties. Agricultural year 1991/92.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
01 CMS 1		5150	6299	6346	6505	6446	7210	5831	5578	5036	6150	5928	6613	5989	6928	6448	6270	5388	6053	7073	5253	6319	6997	6297	4460	6370	6393	6491
02 CMS 2	-24		5362	6926	6000	5748	7076	5894	6954	5592	6313	6284	5919	4700	5638	6384	5683	4112	6428	6658	7084	6509	5322	6494	4324	6199	5979	6674
03 CMS 3	796	375		6025	6618	7907	6594	5766	6067	5798	6386	5414	6265	5447	6047	6693	6303	5694	6091	6012	6126	5817	5881	6993	5827	6370	5692	6596
04 CMS 4N	-64	1035	-199		7100	7052	8283	6788	7267	6650	6402	6484	5797	6424	6081	6695	6683	5180	5888	6169	6680	7415	6391	7046	5717	6272	6873	8037
05 CMS 4C	52	62	347	-73		6542	7255	5787	6989	6339	6735	6245	6819	6549	6470	6668	5776	5823	6651	6635	6462	6900	6671	6009	6610	6042	6646	7392
06 BR 105	-65	-245	1578	-177	-732		7508	6894	7009	7156	7016	7507	7870	5809	6989	7114	5327	7538	6973	6633	7605	7792	6914	8015	8363	8234	6563	7196
07 BR 106	513	894	79	867	-206	-11		6464	7630	6910	7520	6527	7508	6146	7276	6117	7864	7076	7627	7170	5130	6829	6251	6052	6400	7621	6384	8216
08 BR 107	42	622	162	281	-765	281	-330		6089	6422	6602	6328	6869	6183	5954	6318	6142	6139	5684	5952	6678	6817	6488	7176	5727	6008	6263	6592
09 BR 111	-289	1603	386	683	357	322	755	126		6942	6337	6286	7446	5709	6549	6897	6052	5782	6140	7887	6782	6883	6560	6565	5985	6007	6074	6656
10 BR 112	-885	183	56	7	-350	408	-20	399	842		6760	6073	6722	6955	6605	6801	5428	6185	6099	6237	7584	6208	6806	6967	5985	6745	6734	7354
11 CMS 14C	568	1251	992	104	390	615	930	926	581	948		5625	5594	6208	6012	6825	5725	6792	6775	6621	8081	6938	7102	7090	5120	7778	7426	8020
12 CMS 15	-73	796	-404	-241	-522	682	-485	225	107	-164	-266		5521	6148	6453	6441	5129	6613	5745	6415	6695	6644	6610	6126	5439	6866	6056	6520
13 CMS 22	678	501	514	-855	117	1114	568	836	1355	553	-229	-728		7041	5622	6563	6094	6522	6006	6650	6888	6592	5896	4898	6013	7467	7313	7162
14 CMS 23	464	-311	103	176	258	-541	-389	559	5	1194	790	305	1268		6821	6404	5717	6727	5967	7048	5319	6966	6624	5338	5266	6751	5961	6182
15 BR 126	1664	890	967	96	441	903	1005	593	1110	1109	860	877	113	1720		7119	6741	7459	6090	7411	7457	7423	6687	5670	6716	6593	5500	6247
16 CMS 28	574	1026	1002	101	27	419	-765	346	846	694	1063	253	446	691	1671		6935	7982	7274	6487	7599	7433	6893	7365	7369	7441	7509	7840
17 CMS 29	169	101	389	-135	-1093	-1595	757	-56	-226	-904	-264	-1286	-252	-220	1066	651		7544	5974	6523	6470	6636	6499	5992	6183	6830	5651	6982
18 CMS 30	-261	-1021	229	-1188	-594	1069	419	393	-44	301	1255	649	630	1239	2235	2148	1485		6290	5954	6649	6600	6260	5731	6285	6978	6775	6606
19 BR 136	371	1260	590	-517	202	466	934	-98	280	182	1201	-253	78	445	832	1404	-119	646		5461	7007	7073	6338	6604	6550	6560	6117	7348
20 CMS 39	1090	1191	213	-534	-111	-170	179	-126	1727	21	751	120	424	1226	1853	321	130	13	-514		6703	8333	6691	6971	6166	7217	7427	7599
21 CMS 50	-880	1469	176	-175	-437	650	-2009	447	474	1217	2057	247	177	-651	1749	1280	-72	556	879	279		7686	4174	6226	6823	6795	7174	7773
22 S. Elite	272	980	-43	649	89	925	-223	675	662	-71	1004	286	304	1084	1805	1205	171	594	1034	1997	1199		6172	6854	4751	7377	7485	6399
23 Ph 4	1784	628	851	457	692	881	30	1178	1172	1360	2000	1083	441	1574	1902	1499	878	1088	1131	1187	-1481	603		6203	5600	7025	7056	6634
24 Cunha	437	1149	1317	467	-615	1333	-815	1217	529	873	1342	-46	-1205	-358	238	1322	-278	-86	751	821	-77	640	823		5435	7261	7733	7587
25 BA III-Tusón	452	833	2005	990	1840	3536	1386	1622	1804	1746	1226	1117	1763	1422	3136	3177	1767	2320	2549	1868	2375	391	2074	1258		5592	7193	6808
26 Saracura	-256	88	-74	-1077	-1353	784	-12	-717	-796	-114	1262	-75	595	285	393	631	-208	391	-61	298	-277	395	876	465	648		7262	6575
27 Nitroflint	301	401	-217	60	-210	-352	-716	74	-193	408	1445	651	977	30	-167	1234	-850	723	32	1043	639	1038	1443	1471	2785	232		5108
28 Nitrodent	-63	638	226	764	76	-177	657	-56	-71	567	1579	-345	365	-206	122	1102	21	95	81	753	780	-508	560	866	1940	-915	-1845	

the close relationship between heterosis and genetic divergence among the parents. According to Hallauer and Sears (1968) and Vencovsky (1970) the manifestation of specific heterosis is due to large differences between mean gene frequencies in at least some varieties or to the differences between the complementary degree of these frequencies. From a practical point of view, the breeder looks for high yielding specific combinations steming from parents also showing productive potential. For example, the results show that there are crosses such as CMS 39 x S. Elite, CMS 4 N x BR 106 and others shown in Table IV, with higher or similar yields than the two best commercial hybrid (controls) that were P 3072 with 8,344 kg/ha and C 506 with 8,060 kg/ha. The presence of highly productive intervarietal hybrids is promising for both the development of new synthetic varieties and for the formation of superior single hybrids. This is due to the presence of favorable genes in the inbred lines that are a function of the gene frequencies of the parent varieties (Souza Jr., 1981). The most productive cross was 114% higher yielding than the best parent, probably due to the gene frequency differences in the loci which showed some degree of dominance (Moll *et al.*, 1962 and 1965).

When the results of Gama *et al.* (1984) and those of this work are considered (Tables V and VI), it is possible to compare the progress obtained with intrapopulation breeding and intervarietal crossing. Varieties CMS 01, CMS 02 and CMS 03 were not submitted to selection since 1979 when the diallel was carried out, and, for this reason they were considered as a controls (100%) in order to calculate the gain of the CNPMS breeding program. Table V shows the progress obtained in the seven improved varieties in relation to the controls. Comparing the present (1991) assessment data with those of 1979 reported by Gama *et al.* (1984) the genetic advance obtained in ten years of intrapopulation breeding becomes evident regardless of the selection method utilized. Table VI shows the intervarietal hybrid means from experiments carried out in 1979 and 1991. They indicate that the increase in the gene frequencies in the varieties reflected directly on the increase of the yielding ability of the intervarietal hybrids.

It was not possible to establish a clear relationship between the heterosis manifested in the varietal crosses with the different types of endosperm because considerable variation was observed among crosses. For example, BR 105 (flint) when crossed with the flint varieties Saracura and Nitroflint gave higher production than when it was crossed with CMS 28 (dent). The variety CMS 04 N (dent) crossed with BR 106 (semi-dent) and with Nitrodent (dent) produced more than in crosses with other flints varieties (Table IV). This can also be seen in Table VI, where CMS 4N (dent) x BR 106 (semi-dent) had the highest yield while CMS 4N (dent) x CMS 14C (semi-flint) had the lowest. Similar results were reported and commented by Hallauer and Miranda Filho (1981). There does not seem to exist a relationship between endosperm type and heterosis expression.

Table V - Selection results obtained as percentages of improvement over the average of the non-improved varieties [CMS 01, CMS 02, CMS 03, representing controls (100%)] assessed in 1979[1] and 1991. Sete Lagoas, MG, 1991/92.

Varieties	CMS 01		CMS 02		CMS 03	
	1979	1991	1979	1991	1979	1991
CMS 04N	110	125	110	130	111	134
BR 105	102	129	103	129	104	138
BR 106	125	135	125	163	126	145
BR 107	103	103	103	118	104	111
BR 111	106	106	106	110	107	114
BR 112	83	108	83	124	83	116
CMS 14C	119	96	119	142	120	103
Mean (kg/ha)	5,028	5,690	5,031	4,655	4,993	5,318

[1]Gama *et al.*, 1984.

Table VI - Ear weight mean values (kg/ha) from intervarietal crosses assessed in 1979 (below the diagonal)[1] and in 1991 (above the diagonal) between the seven maize varieties most improved in the breeding program of CNPMS. Sete Lagoas, MG, 1991/92.

Varieties	CMS 4N	BR 105	BR 106	BR 107	BR 111	BR112	CMS 14C
CMS 4N		7052	8283	6788	7267	6650	6402
BR 105	6437		7508	6894	7009	7156	7016
BR 106	6083	7336		6464	7630	6910	7520
BR 107	5959	6024	5662		6089	6422	6602
BR 111	6102	5704	6545	5865		6942	6337
BR 112	5852	5810	6752	6249	6467		6760
CMS 14C	5664	5664	7162	5474	6030	5866	

[1]Gama *et al.*, 1984.

RESUMO

Foram avaliadas 28 variedades de milho de diferentes ciclos e tipos de endosperma juntamente com 378 F_1's e sete híbridos comerciais (testemunhas) em três ambientes: Sete Lagoas-MG, Goiânia-GO e Londrina-PR. Estas variedades representam germoplasmas adaptados a diferentes áreas do Brasil e que vem sendo melhoradas no Centro Nacional de Pesquisa de Milho e Sorgo em Sete Lagoas-MG. A análise conjunta de variância para o caráter peso de espigas mostrou significância ($P < 0,01$) para ambientes, entradas, variedades, heterose, heterose média, heterose de variedades, heterose específica, ambientes

x entradas e ambientes x variedades. A produção média das variedades variou de 2.322 kg/ha a 7.704 kg/ha, enquanto que a dos híbridos intervarietais variou de 4.112 kg/ha a 8.363 kg/ha. A heterose média foi de 489 kg/ha e a heterose varietal oscilou de -589 kg/ha a 1.339 kg/ha. A maior heterose específica foi obtida do cruzamento BR 105 x Ba III - Tusón. Verificou-se a presença de híbridos intervarietais mais produtivos que a melhor testemunha, tornando-se, do ponto de vista prático, bastante promissor para os programas de melhoramento, uma vez que poderão ser formadas novas variedades sintéticas ou aproveitar estas variedades para iniciar programas para obtenção de híbridos. Não se encontrou associação entre a expressão da heterose com as diferenças no tipo de endosperma.

REFERENCES

Gama, E.E.G., Viana, R.T., Naspolini, V. and Magnavaca, R. (1984). Heterosis for four characters in nineteen populations of maize (*Zea mays* L.). *Egyptian J. Genet. Cytol. 13*: 69-80.

Gardner, C.O. and Eberhart, S.A. (1966). Analysis and interpretations of the variety cross diallel and related populations. *Biometrics 22*: 429-452.

Gardner, C.O. and Paterniani, E. (1967). A genetic model used to evaluate the breeding potential of open-pollinated varieties of corn. *Ciência e Cultura 19*: 95-101.

Hallauer, A.R. (1972). Third phase in the yield evaluation of synthetic varieties of maize. *Crop. Sci. 12*: 16-18.

Hallauer, A.R. and Miranda Filho, J.B. (1981). *Quantitative Genetics in Maize Breeding*. Iowa State University Press, Ames, Iowa, pp. 468.

Hallauer, A.R. and Sears, J.H. (1968). Second phase in the evaluation of synthetic varieties of maize for yield. *Crop. Sci. 8*: 448-451.

Lopes, M.A., Gama, E.E.G., Viana, R.T. and Souza, T.R.P. (1985). Heterose e capacidade de combinação para produção de espigas em cruzamentos dialélicos de seis variedades de milho. *Pesq. Agrop. Bras. 20*: 349-354.

Moll, R.H., Salhuana, W.S. and Robinson, H.F. (1962). Heterosis and genetic diversity in variety crosses of maize. *Crop. Sci.* 2: 197-198.

Moll, R.H., Lonnquist, J.H., Fortuno, J.V. and Johnson, E.C. (1965). The relationship of heterosis and genetic divergence in maize. *Genetics 52*: 139-144.

Morais, A.R., Oliveira, A.C., Gama, E.E.G. and Souza Junior, C.L. (1991). A method for combined analysis of the diallel crosses repeated in several environments. *Pesq. Agrop. Bras. 26*: 371-381.

Naspolini, V., Gama, E.E.G., Viana, R.T. and Moro, J.R. (1981). General and specific combining ability for yield in a diallel cross among 18 maize populations (*Zea mays* L.). *J. Genetics 4*: 571-577.

Parentoni, S.N., Santos, M.X., Magnavaca, R., Gama, E.E.G., Pacheco, C.A.P. and Lopes, M.A. (1990). Productividad y heterosis en cruzamentos dialelícos de diez problaciones precoces de maiz. In: *XIII Reunión de Maiceros de la zona Andína*, 1988, Chyclaio, Peru, pp. 33-48.

Paterniani, E. and Miranda Filho, J.B. (1987). Melhoramento de populações. In: *Melhoramento e Produção de Milho* (Paterniani, E. and Viegas, G.P., eds.). Edited by Fundação Cargill, ESALQ-USP, Piracicaba, pp. 202-246.

Souza Jr., C.L. (1981). Análise de cruzamentos dialélicos e predição de compostos de milho (*Zea mays* L.). braquítico. Master's Thesis. Universidade de São Paulo, Piracicaba.

Sprague, G.F. and Tatum, L.A. (1942). General vs. specific combining ability in single crosses of corn. *Agron. J. 34*: 923-932.

Troyer, A.F. and Hallauer, A.R. (1968). Analysis of a set of early flint varieties of maize. *Crop. Sci. 8*: 581-584.

Vencovsky, R. (1970). Alguns aspectos teóricos e aplicados relativos a cruzamentos dialélicos de variedades. Associate Professor Thesis, Universidade de São Paulo, Piracicaba.

(Received October 20, 1993)