Rev. Brasil. Genet. 15, 3, 631-642 (1992)
(Brazil. J. Genetics)

EXOTIC GERMPLASMS INTRODUCED IN A BRAZILIAN MAIZE BREEDING PROGRAM

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ABSTRACT

Fifteen maize populations, representing temperate and temperate x tropical germplasms were introduced from the United States. These populations and a check population (ESALQ-PB1) were evaluated in a randomized block experiment and the following traits were measured: PH-plant height, EH-ear height, TB-tassel branch number, EL-ear length, ED-ear diameter, RN-kernel row number, KR-kernels per row, EW - ear weight, GW - grain weight, and KW - 100 kernels weight. The exotic populations showed an average performance level lower than the check for all traits, except RN. Part of the variation among populations was attributed to differential adaptation to brazilian conditions. The positive phenotypic correlation among populations for all combinations of traits also gave some evidence of differential adaptation.

The exotic populations were divided into two groups and the following composite populations were planned: CEX-i, from crosses Exotics-I x ESALQ-PB1; CEX-2, from crosses Exotics-II x ESALQ-PB1; CX-3, from crosses among populations of group-I (Exotics-I); and CEX-4, from crosses among populations of group-II (Exotics-II). On average, the populations of Exotics-I showed a higher performance level than Exotics-II for all traits, except KW. Such differences were reflected in the predicted means of composites for all traits; prediction was based on the mean of parental varieties and on the hypothetical average heterosis, expressed as a proportion of varietal mean. For grain yield and 20% expected average heterosis, the predicted composite means were: 90.6%, 87.1%, 70.5% and 63.3% of ESALQ-PB1 for CEX-1, CEX-2, CEX-3 and CEX-4, respectively.

INTRODUCTION

Although *Zea mays* L. originated in Mexico and Central America it spread considerably during the post-Colombian era and became an important crop throughout

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the world (Hallauer and Miranda Filho, 1988). In this century, with the rapid development of genetic and breeding methodologies, germplasm exchange has greatly contributed to maize improvement in many parts of the world. In Brazil, after 1940, the introduction of exotic germplasm, represented mainly by Tuxpeño and related races from Mexico, allowed the formation of outstanding semi-dent hybrids (Miranda Filho and Viegas, 1987; Hallauer and Miranda Filho, 1988). More recently, Moro *et al.* (1981) reported on new introductions of maize germplasm from CIMMYT (Mexico). To a lesser extent many introductions have been made by public and private institutions (Lima *et al.*, 1982; Miranda Filho and Vencovsky, 1984). The Brazilian Germplasm Bank (CENARGEN-EMBRAPA) maintains a large collection of germplasms, including exotics and South-American races previously described by Brieger *et al.* (1958) and Paterniani and Goodman (1977).

Many authors (Brown, 1953; Welhausen, 1956, 1965; Brown and Goodman, 1977; Hallauer, 1978; Duvick, 1981) have emphasized the importance of exotic germplasm introductions in maize breeding programs. Hallauer and Miranda Filho (1988) have summarized much information on races, germplasm banks and other relevant aspects of germplasm utilization in breeding programs. We report on the characterization of fifteen populations, representing germplasms of tropical, temperate and tropical x temperate origins, which may be useful in breeding tropical maize.

MATERIAL AND METHODS

Fifteen exotic maize populations were introduced into the maize breeding program of the Department of Genetics (ESALQ-USP). They were designated as EX-1 to EX-15. These were introduced from the United States (Iowa, Indiana and Wisconsin), where some of them were used as exotic or semi-exotic populations, obtained from tropical germplasm. The introduced samples were multiplied through biparental crosses and from each pollinated ear an equal number of seeds was taken to represent each sample. This procedure assures an effective population size that is twice that obtained with open-pollination and a random seed samples (Hallauer and Miranda Filho, 1988). The number of pollinated ears and the expected effective number for a constant population size are shown in Table I, for all populations and with their original designations.

The populations were evaluated in a completely randomized block experiment with two replications in plots 2.0 m long, spaced 1.0 m apart, with 10 plants per plot after thinning. The following traits were analyzed: PH - plant height (cm); EH - ear height (cm); TB - tassel branch number; EL - ear length (cm); ED - ear diameter (cm); RN - kernel row number; KR - kernels per row; EW - ear weight (g); GW - grain weight (g); KW - 100 kernels weight (g). All the traits were expressed on an individual plant basis.

Table I - Number of pollinated ears (N) and expected effective number (Ne) for fifteen populations, divided into two groups.

Population	Group	Original designation[a]	N	Ne
EX-1	I	BSSS-S2 (S) C2	14	28
EX-2	I	Corn Belt x Brazilian Syn	10	20
EX-3	II	Kenya Composite	11	22
EX-4	I	BSTL (S2) C2	7	14
EX-5	II	Early x Tropical	11	22
EX-6	II	Early x Colombian	9	18
EX-7	II	BS-7 x CBK (Kitale)	9	18
EX-8	I	BSSS (R) C7	28	56
EX-9	I	Corn Belt x Mexican Syn	23	46
EX-10	I	Corn Belt x Caribean	8	16
EX-11	I	BS-17	19	38
EX-12	I	BS-8 x SK (Kitale)	17	34
EX-13	II	Colus 71-428-612	22	44
EX-14	II	Antigua 2D x (BS-10 x BS-14)	18	36
EX-15	II	ETO x CBC (LAF)	19	38

[a]As identified in the samples received.

The next step following the experimental evaluation of the exotic populations, was the synthesis of new populations (composites) to be used in recurrent selection programs. The following composite populations were planned: CEX-1, resulting from intercrossing the hybrids between group-I (Exotics-I) x ESALQ-PB1; CEX-2, resulting from intercrossing the hybrids between group-II (Exotics-II) x ESALQ-PB1; CEX-3, resulting from intercrosses among hybrids of group-I; and CEX-4, resulting from intercrosses among hybrids of group-II. Therefore, CEX-1 and CEX-2 share 50% of ESALQ-PB1 and 50% of exotic germplasm, while CEX-3 and CEX-4 have only exotic germplasm. The prediction of composite means were, according to Hallauer and Miranda Filho (1988):

CEX-1 and CEX-2: $$Y_{CO} = 1/2\,(\overline{Y}_O + \overline{Y}_V) + 1/2\,\overline{h}_O + \frac{n-1}{4n}\,\overline{h}_V$$

CEX-3 and CEX-4: $$Y_{CO} = \overline{Y}_V + \frac{n-1}{n}\,\overline{h}_V$$

where $\overline{Y}_o$ and $\overline{Y}_v$ represent the mean of the base population (ESALQ-PB1) and the mean of groups of populations (Exotic-I in CEX-1 and CEX-3 and Exotic-II in CEX-2 and CEX-4); $\overline{h}_o$ is the average heterosis in the crosses ESALQ-PB1 x Exotics (for each group); $\overline{h}_v$ is the average heterosis among crosses within groups of exotics); and n is the number of exotic populations (n = 8 in CEX-1 and CEX-3 and n = 7 in CEX-2 and CEX-3). For the purpose of this work $\overline{h}_o$ and $\overline{h}_v$ were taken as proportions of $1/2\ (\overline{Y}_o + \overline{Y}_v)$ and $\overline{Y}_v$, respectively.

RESULTS AND DISCUSSION

The fifteen exotic populations shown in Table I were introduced from the United States, where most of them were used alone as exotics (tropical germplasm) or semi-exotics (temperate x tropical), with the purpose of increasing genetic variability in the Corn Belt germplasm (Wellhausen, 1956, 1965). Our purpose was to use these populations in the opposite direction, i.e., to increase the genetic variability in Brazil, by using germplasms from temperate or temperate x tropical origins. The characterization of the introduced populations and the local and adapted variety ESALQ-PB1 is shown in Table II, where the means of ten traits are presented on an individual plant basis.

The relatively poor performance of the exotic populations is a clear indication of a lack of adaptation to the environment at Piracicaba (SP). Both groups of exotics show, on average, a lower mean than ESALQ-PB1 for all traits, except for number of kernel rows. Also, the means in group-I were consistently higher than in group-II, for all traits. For ear weight (EW) and grain weight (GW) the low average performance was probably due to a strong lack of adaptation, because of the intrinsic low heritability of these traits. For plant and ear height it is difficult to assess the level of environmental effect because most of the introduced populations are known to exhibit low plant height and ear placement. For traits of higher heritability (TB, EL, ED, RN, KR and KW) the relative values were higher than for other traits but also do not allow an exact quantification of the environmental effect. Particularly for grain yield, which is the trait of primary interest in our program, some exotic populations were outstanding, such as EX-10 (139.6 g/plant; 90% of ESALQ-PB1) in group-I and EX-14 (122.2 g/plant; 78.8% of ESALQ-PB1) in group-II.

Another trait of particular interest in our program is the ear placement (EH/PH). Because it is a relative value, it is not expected to be highly affected by environmental changes; the means for both group-I (0.45) and group-II (0.42) were smaller than for ESALQ-PB1 (0.58), indicating that introgression of the exotic materials may contribute to decrease the ear placement in Brazilian germplasms. The tassel branch number also was much smaller in the exotics than in ESALQ-PB1 and could also contribute to the breeding of more efficient maize plants. Ear placement and tassel size seem to be

Table II - Means of ten traits in sixteen populations.

Population	Group	PH	EH	TB	EL	ED	RN	KR	EW	GW	KW
Ex-1	I	110.0	40.4	9.3	16.0	4.0	14.5	25.0	89.5	68.3	22.0
Ex-2	I	170.4	83.9	18.9	18.2	4.3	13.0	32.1	134.9	108.9	26.0
Ex-3	II	101.9	29.7	9.4	12.4	3.5	11.0	14.7	50.7	36.5	25.5
Ex-4	I	123.4	54.0	10.2	15.0	4.0	13.3	26.5	96.2	79.5	22.5
Ex-5	II	102.8	49.2	6.9	14.1	3.5	12.2	19.6	59.3	45.2	23.0
Ex-6	II	149.6	74.2	18.3	17.2	4.5	14.4	28.0	145.8	114.1	28.5
Ex-7	II	133.5	57.2	11.8	15.0	4.0	13.8	24.1	102.6	83.2	26.5
Ex-8	I	142.9	63.3	22.5	16.0	4.7	15.0	29.6	144.4	117.1	28.5
Ex-9	I	152.9	77.5	16.9	16.2	4.1	13.0	31.7	102.2	83.9	22.5
Ex-10	I	159.8	75.4	20.2	17.1	4.8	14.2	29.0	168.7	139.6	32.5
Ex-11	I	130.4	52.5	11.0	14.6	3.5	13.0	20.8	119.5	54.2	21.0
Ex-12	I	151.8	65.6	17.6	16.9	4.1	12.3	31.1	110.0	93.5	27.5
Ex-13	II	127.0	51.0	14.5	16.3	4.1	13.0	27.7	117.9	96.0	28.0
Ex-14	II	131.0	52.2	10.4	17.9	4.6	14.0	32.5	149.9	122.2	26.0
Ex-15	II	135.5	58.8	19.0	15.6	4.3	14.6	31.8	109.0	89.4	20.5
ESALQ-PB1		183.5	105.8	20.4	18.8	4.8	13.2	38.7	194.0	155.1	29.5
Mean		137.9	61.9	14.8	16.1	4.2	13.4	27.7	118.4	92.9	25.3
Exotics-I		142.7	64.1	15.8	16.2	4.2	13.5	28.2	120.6	93.1	25.3
%		77.8	60.6	77.5	86.4	86.8	102.5	72.9	62.2	60.0	85.8
Exotics-II		125.9	53.2	12.9	15.5	4.1	13.3	25.5	105.0	83.8	25.4
%		68.6	50.2	63.2	82.3	84.5	100.6	65.8	54.1	54.0	86.2

% - in percent of ESALQ-PB1.

positively correlated and higher yields may be attained by combining lower ear placement and smaller tassels (Geraldi *et al.*, 1985; Souza Jr. *et al.*, 1985).

The differential performance of the exotic populations for the several traits is evidence for their differential adaptation to our conditions. An exact quantitative measure of adaptation was not possible because no information was available on the performance of the populations in their places of origin. For ear height, for example, the range was 32.2% to 79.3% of the ESALQ-PB1 value. Although the populations may show lower ear heights at their places of origin, part of the observed variation is probably due to differential adaptation. For grain weight, which is a trait of low heritability, there is more evidence of differential adaptation; the range among the populations was from 23.5% to 90.0% of ESALQ-PB1. Because the exotics are all breeding populations, it is reasonable to suppose that their yield performance at their origin would be at least at the same level or not much smaller than ESALQ-PB1 under our conditions, so that a greater part of the observed variation may be attributed to differential adaptation. Therefore, one can roughly use the performance level of the populations as a measure of the degree of adaptation to the conditions of our experiment. For this purpose, a trait of low heritability such as grain yield is more sensitive for discriminating among populations with respect to their adaptive values. In this sense the populations EX-3 would be the least adapted and EX-10 the most adapted relative to ESALQ-PB1, under our conditions.

The phenotypic correlation coefficients shown in Table III indicate a positive association for all combinations of traits. They also indicate the differential environmental effect in the populations and that it affects all traits in the same direction to a greater or lesser extent, according to the degree of adaptation of each population. Although we dealt with a fixed set of genetic materials, the correlation coefficient was used as a measure of association between traits. Some combinations of traits are inherently positive as measured in random samples of normally distributed genotypic values. Nevertheless, the correlation coefficients herein observed were always higher than those reported by some authors. Hallauer and Miranda Filho (1988) summarized the

Tabela III - Phenotypic correlation between means in combinations of ten traits (above diagonal) as compared to genetic correlations (below diagonal).

Traits	PH	EH	TB	EL	ED	RN	KR	EW	GW	KW
PH	1.00	0.95	0.83	0.82	0.73	0.25	0.82	0.83	0.82	0.53
EH	0.81	1.00	0.75	0.78	0.67	0.22	0.80	0.77	0.78	0.49
TB	-	-	1.00	0.62	0.77	0.43	0.71	0.71	0.75	0.60
EL	0.22	0.08	-	1.00	0.82	0.44	0.90	0.85	0.88	0.36
ED	0.03	0.08	-	-0.01	1.00	0.66	0.82	0.87	0.96	0.53
RN	0.00	0.25	-	-0.16	0.57	1.00	0.46	0.52	0.53	0.06
KR	0.25	0.22	-	-	0.57	-	1.00	0.78	0.85	0.24
EW	-	-	-0.65[b]	-	-	-	-	1.00	0.94	0.52
GW	0.26	0.31	-	0.38	0.41	0.24	0.25	-	1.00	0.59
KW	0.05	0.05	-	-0.03	0.21	-0.33	0.27	-	0.25	1.00

[a]Adapted from Hallauer and Miranda Filho (1988), except [b](from Geraldi *et al.*, 1985).

genetic correlation coefficients for some combinations of traits. For yield and plant height, for example, the correlation coefficient was 0.26, for the average of 23 studies; the corresponding phenotypic correlation for the exotic populations was 0.782. Other similar comparisons can be seen in Table III by taking the phenotypic correlations and the genetic correlations summarized by Hallauer and Miranda Filho (1988).

Table IV shows the analysis of variance for all traits in all populations (check included). Highly significant differences were observed for all traits among populations where the main cause of variation was the contrast exotics vs check. The orthogonal partition of the sums of squares to analyse the two groups of exotics showed significant differences between groups only for PH, EH and TB; the means were however consistently higher for group-I. On the other hand, in group-II, there were significant differences at $P < 0.05$ for all traits and at $P < 0.01$ for TB, EL, RN, KR and KW. As already mentioned, the significant differences among the exotic populations is partly due to differential adaptation.

Hallauer (1978) emphasized that selection can be practiced within exotic germplasms or within populations formed by crossing exotic x adapted varieties. Following the first phase for evaluation of the most important traits in the exotic populations, the next step would be the synthesis of new populations or composites. Thus, according to procedures given by Hallauer and Miranda Filho (1988), the following composite populations were planned, CEX-1, from intercrossing hybrids between Exotics-I and ESALQ-PB1; CEX-2, from intercrossing hybrids between Exotics-II and ESALQ-PB1; CEX-3, from intercrossing hybrids among populations of group-I; and CEX-4, from intercrossing hybrids among populations of group-II. Then, for CEX-1 and CEX-2, 50% of the genes in the composite are from the adapted population ESALQ-PB1, and the other 50% are shared equally by the exotics in each group: 1/16 for each exotic population in CEX-1 and 1/14 for each exotic population in CEX-2. In CEX-3 and CEX-4, the exotic populations participate with equal proportions: 1/8 in CEX-3 and 1/7 in CEX-4.

The formulas given by Hallauer and Miranda Filho (1988) for predicting means of composites require information on the performance of varieties and variety crosses. Nevertheless, the formulas can also be expressed as a function of the varietal means and the average heterosis of all crosses. Since we did not have information on variety crosses, our predictions were based on hypothetical average heterosis, expressed as proportion of the variety mean. Except for yield which is a low heritability trait, all other traits are in the range of medium to high heritability (Geraldi *et al.*, 1985; Hallauer and Miranda Filho, 1988). Non-additive gene effects are less important in the expression of those traits and heterosis is generally of a low magnitude. Miranda Filho and Vencovsky (1984) reported an average heterosis of the order of 3.1% for plant height and 3.7% for ear height in variety diallel crosses. For the same set of crosses, the average heterosis for ear traits

Table IV - Analysis of variance of ten traits evaluated in sixteen maize populations.

Source	df	PH	EH	TB[1]	EL[2]	ED[3]	RN[2]	KR[1]	EW	GW	KW
Populations	15	1060.5**	674.7**	486.5**	539.6**	368.8**	220.6**	691.0**	2802.2**	2151.6**	235.3**
Exotics	14	819.1**	429.1**	473.7**	464.0	332.6**	235.8**	555.0*	2131.1*	1715.9*	229.2**
Ex-I	7	810.3**	428.6**	500.2**	268.2	337.1*	173.8*	306.5	1456.8	1539.5	322.0**
Ex-II	6	615.2*	353.3*	414.5**	594.1**	367.4*	339.3**	844.4*	2968.3*	2099.1*	159.0**
(I vs II)	1	2103.1**	887.1**	643.1**	453.7	93.0	47.7	558.1	1828.8	650.5	0.9
Ex vs check	1	4440.2**	4113.1**	668.1**	1598.7**	875.5**	8.5	2594.5**	12196.8**	8252.7**	319.8**
Error	15	189.0	93.7	66.8	108.1	88.0	52.5	184.1	766.1	589.0	17.2
Mean		137.9	61.9	14.8	16.1	4.2	13.4	27.7	118.4	92.9	25.6
CV %		10.0	15.6	17.5	6.5	7.1	5.4	15.5	23.4	26.1	5.1

[1,2,3]Mean squares were multiplied by 10, 10^2 and 10^3, respectively.

*,** Significance level at $P < 0.05$ and $P < 0.01$, respectively.

were of the order of: 1.8% for RN, 6.1% for KR, 4.0% for EL, 3.2% for ED, 12.2% for EW, 12.9% for GW and 5.3% for KW (Miranda Filho, 1978). Therefore, the predicted means for composites were obtained for average heterosis equal to 0.0 and 0.1, expressed as a proportion of the variety mean. The predicted means for all traits are shown in Table V. For grain weight, which generally showed average heterosis higher than 10%, the predicted means also were obtained for h in the range of 0.0 to 0.5, as a proportion of the varietal mean, and are shown graphically in Figure 1 for the four composites. For example, for an average heterosis of 20% the predicted means in percent of ESALQ-PB1 are: 90.6%, 87.1%, 70.5% and 63.3% for CEX-1, CEX-2, CEX-3 and CEX-4, respectively. An average heterosis of 20% is close to the average heterosis of 1,394 variety crosses summarized by Hallauer and Miranda Filho (1988). Nevertheless, the heterosis for yield in crosses of diverse origins can be higher than 20%, as shown by some authors reporting average heterosis of the order of 33.0% (Paterniani and Lonquist, 1963), 59.2% (Wellhausen, 1965), 40.5% (Paterniani, 1967), 45.5% (Castro *et al.*, 1968), 34.8% (Paterniani, 1968), 72.0% (Troyer and Hallauer, 1968). From Figure 1, it can be seen that the predicted mean yield would be close to ESALQ-PB1 for an average heterosis of 37.5% in CEX-1 and 46.0% in CEX-2. The composites formed only with exotic populations (CEX-3 and CEX-4) would show a smaller yielding potential; for a 50% average heterosis their expected yield would be 86.3% and 77.8% in relation to ESALQ-PB1, respectively.

Table V - Expected means of ten traits in composites formed from exotic populations.

Trait	CEX-1		CEX-2		CEX-3		CEX-4	
	p - 0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1
PH	163.1	174.4	154.7	165.7	142.7	155.2	125.9	136.7
EH	85.0	90.6	79.5	85.6	64.1	69.7	53.2	57.8
TB	18.1	19.4	16.7	17.8	15.8	17.2	12.9	14.0
EL	17.5	18.7	17.2	18.3	16.2	17.6	15.5	16.8
ED	4.5	4.8	4.5	4.8	4.2	4.6	4.1	4.5
RN	13.4	14.3	13.3	14.2	13.5	14.7	13.3	14.4
KR	33.5	35.7	32.1	34.3	28.2	30.7	25.5	27.7
EW	157.3	167.8	149.5	159.2	120.6	131.2	105.0	114.0
GW	124.1	132.3	119.5	127.2	93.1	101.2	83.8	91.0
KW	27.4	29.3	27.5	29.4	25.3	27.5	25.4	27.6

p: proportion of average heterosis expressed in crosses within groups (Ex-I and Ex-II) and between groups (Ex-1 x ESALQ-PB1 and Ex-II x ESALQ-PB1).

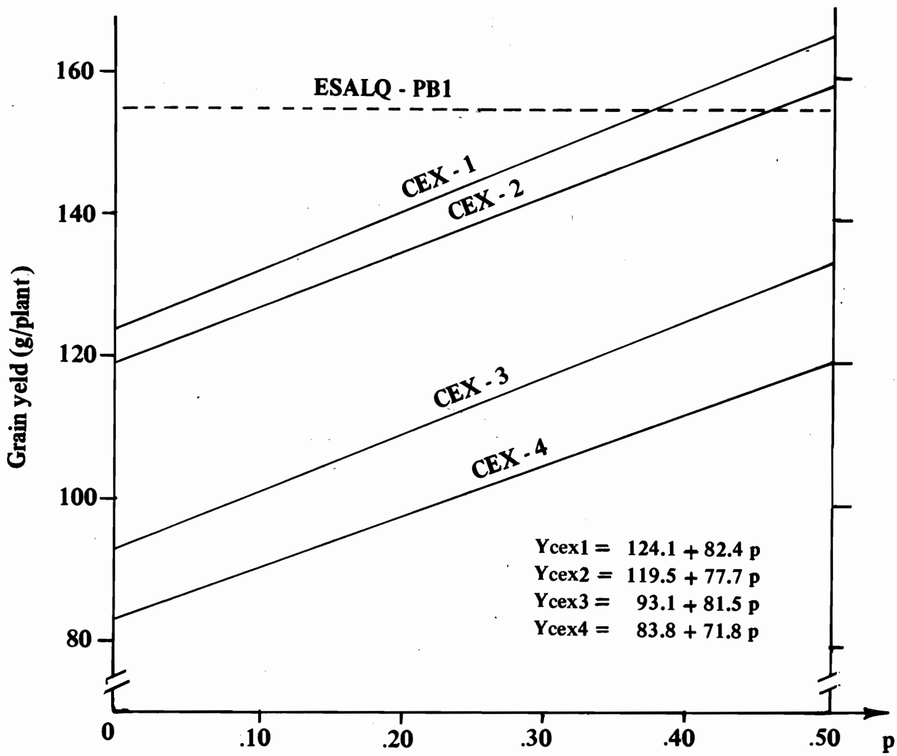

Figure 1 - Expected means for grain yield in four composites for varyings levels of p (proportion of average heterosis).

After three or four generations of random mating for recombination the newly formed composites will undergo recurrent selection for yield and other important agronomic traits. During the recombination period it is possible that the performance of the new composites will be better than that indicated by the predicted means, because mild selection for agronomic traits will be practiced and natural selection also is expected to occur which will enhance the level of adaptation at the population level.

ACKNOWLEDGMENT

Publication supported by FAPESP.

RESUMO

Quinze populações foram introduzidas dos Estados Unidos, representando germoplasmas de origem temperado e tropical x temperado. As populações e a testemunha (ESALQ-PB1) foram avaliadas em experimento em blocos casualizados e os seguintes caracteres foram medidos: altura da planta (PH), altura da espiga (EH), número de ramificações do pendão (TB), comprimento da espiga (EL), diâmetro da espiga (ED), número de fileiras de grãos (RN), número de grãos por fileira (KR), peso da espiga (EW), peso de grãos (GW) e peso de 100 grãos (KW). As médias das populações exóticas foram menores que a testemunha para todos os caracteres, exceto número de fileiras. Parte da variação entre as populações foi atribuída a adaptação diferencial às nossas condições. A correlação fenotípica positiva entre populações para todos os caracteres também foi uma leve evidência de adaptação diferencial.

As populações exóticas foram divididas em dois grupos e foi planejada a obtenção dos seguintes compostos: CEX-1, a partir de cruzamentos Exotics-I x ESALQ-PB1; CEX-2, a partir de cruzamentos Exotics-II x ESALQ-PB1; CEX-3, a partir de cruzamentos entre as populações do grupo I (Exotics-I); CEX-4, a partir de cruzamentos entre populações do grupo II (Exotics-II). Em média, as populações dos grupo I mostraram maiores valores do que as do grupo II, para todos os caracteres, exceto peso de 100 grãos. Estas diferenças refletiram nas médias preditas de compostos para todos os caracteres; a predição foi baseada na média das variedades parentais e na heterose média hipotética expressa em proporção da média de variedades. Para o peso de grãos e 20% de heterose média esperada, as médias preditas dos compostos foram: 90.6%, 87.1%, 70.5% e 63.3% de ESALQ-PB1 para CEX-1, CEX-2, CEX-3 e CEX-4, respectivamente.

REFERENCES

Brieger, F.G., Gurgel, J.T.A., Paterniani, E., Blumenschein, A. and Alleoni, M.R. (1958). Races of maize in Brazil and other eastern South American countries. *NAS-NRC Publ.* 593, Washington, D.C.

Brown, W.L. (1953). Maize of the West Indies. *Trop. Agric. 30*: 141-170.

Brown, W.L. and Goodman, M.M. (1977). Races of Maize. In: *Corn and Corn Improvement* (Sprague, G.F., ed.). Amer. Soc. Agron. Madison (Wis.).

Castro, M., Gardner, C.O. and Lonnquist, J.H. (1968). Cumulative gene effects and the nature of heterosis in maize crosses involving genetically divergent races. *Crop. Sci. 8*: 97-101.

Duvick, D.N. (1981). Genetic diversity in major crops on the farm and in reserve. In: *Proceedings of Thirteenth Intern. Bot. Congress*, Sidney, Australia.

Geraldi, I.O., Miranda Filho, J.B. and Vencovsky, R. (1985). Estimates of genetic parameters for tassel characteres in maize (*Zea mays* L.) and breeding perspectives. *Maydica 30*: 1-14.

Hallauer, A.R. (1978). Potential of exotic germplasm for maize improvement. In: *Maize Genetics and Breeding* (Walden, W.L., ed.).

Hallauer, A.R. and Miranda Filho, J.B. (1988). *Quantitative Genetics in Maize Breeding*. Iowa State Univ. Press., Ames (Iowa), 468 p. (2nd edition).

Lima, M., Gimenes Fernandes, N., Miranda Filho, J.B. and Pereira, J.C.V.A. (1982). Introduction of maize (*Zea mays* L.) germplasms as sources for downy mildew (*Peronosclerospora sorghi*) resistance. *Maydica 27*: 159-168.

Miranda Filho, J.B. (1978). Heterosis for ear traits in intervarietal diallel crosses. *Rel. Cient. Inst. Genética* (ESALQ-USP) *12*: 131-137 (Abstract).

Miranda Filho, J.B. and Vencovsky, R. (1984). Analysis of diallel crosses among open-pollinated varieties of maize (*Zea mays* L.). *Maydica 29*: 217-234.

Miranda Filho, J.B. and Viegas, G.P. (1987). Milho Híbrido. In: *Melhoramento e Produção do Milho* (Paterniani, E. and Viegas, G.P., eds.). Edited by Fundação Cargill.

Moro, J.R., Naspolini Filho, V., Vianna, R.T. and Gama, E.E.G. (1981). Introdução de novos germoplasmas de milho no Brasil. *Pesq. Agrop. Bras. 16*: 867-882.

Paterniani, E. (1967). Cruzamentos intervarietais de milho. *Rel. Cient. Inst. Genética* (ESALQ-USP) *1*: 49-50.

Paterniani, E. (1968). Cruzamentos interraciais de milho. *Rel. Cient. Inst. Genética* (ESALQ-USP) 2: 108-110.

Paterniani, E. and Goodman, M.M. (1977). *Races of maize in Brazil and adjacent areas.* CIMMYT (Mexico).

Paterniani, E. and Lonquist, J.H. (1963). Heterosis in interracial crosses of corn (*Zea mays* L.). *Crop. Sci. 3*: 504-507.

Souza Junior, C.L., Geraldi, I.O. and Zinsly, J.R. (1985). Influences of tassel size on the expression of prolificacy in maize (*Zea mays* L.). *Maydica 30*: 321-328.

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

Wellhausen, E.J. (1956). Improving American corn with exotic germplasm. *Proc. Annu. Hybrid Corn Ind. Res. Conf. 11*: 85-96.

Wellhausen, E.J. (1965). Exotic germplasm for improvement of Corn Belt maize. *Proc. Annu. Hybrid Corn Ind. Res. Conf. 20*: 31-45.

(Received July 16, 1991)