PAB Pesquisa Agropecuária Brasileira

Genetics/ Original Article

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Heterosis and genetic distance in intervarietal corn hybrids

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Received
October 27, 2017

Accepted
August 21, 2019

How to cite
BARETTA, D.; NARDINO, M.; CARVALHO, I.R.; PELEGRIN, A.J. de; FERRARI, M.; OLIVEIRA, V.F. de; SZARESKI, V.J.; OLIVEIRA, A.C. de; BARROS, W.S.; SOUZA, V.Q. de; MAIA, L.C. da. Heterosis and genetic distance in intervarietal corn hybrids. **Pesquisa Agropecuária Brasileira**, v.54, e00265, 2019. DOI: https://doi.org/10.1590/S1678-3921.pab2019.v54.00265.

Abstract – The objective of this work was to evaluate the performance of intervarietal corn (*Zea mays*) hybrids with topcross crosses between landrace populations, and to confirm whether genetic dissimilarity between populations is correlated with the heterosis of the intervarietal hybrids in the field. Nine topcross hybrids were evaluated with their tester 'BRS Planalto', and the following landrace populations were used as parents: Argentino Branco, Dente de Ouro, Amarelão, Criolão, Caiano Rajado, Branco Oito Carreiras, Branco Roxo Índio, Cateto Branco, and Argentino Amarelo. The tester 'BRS Planalto' and the topcross hybrids Branco Oito Carreiras x 'BRS Planalto' and Criolão x 'BRS Planalto' showed higher per se potential for grain yield. The topcross hybrid Branco Oito Carreiras x 'BRS Planalto' showed a better performance for number of grains per row, grain weight, and ear diameter, whereas Criolão x 'BRS Planalto' displayed a better performance for the number of grains per row and ear length. Greater estimates of genetic distance did not necessarily result in greater heterosis values and were exclusively correlated with grain ear length. Therefore, it is not possible to predict the effects of high heterosis on grain yield, based on the genetic distance between the populations involved in the crosses.

Index terms: *Zea mays*, genetic dissimilarity, heterosis, landraces, topcross.

Heterose e distância genética em híbridos intervarietais de milho

Resumo – O objetivo deste trabalho foi avaliar o desempenho de híbridos de milho (*Zea mays*) intervarietais, a partir de cruzamentos topcross entre populações crioulas, além de confirmar se a dissimilaridade genética entre as populações é correlacionada à heterose dos híbridos intervarietais no campo. Nove híbridos topcross foram avaliados com seu testador 'BRS Planalto', e as seguintes populações crioulas foram utilizadas como genitores: Argentino Branco, Dente de Ouro, Amarelão, Criolão, Caiano Rajado, Branco Oito Carreiras, Branco Roxo Índio, Cateto Branco e Argentino Amarelo. O testador 'BRS Planalto' e os híbridos topcross Branco Oito Carreiras x 'BRS Planalto' e Criolão x 'BRS Planalto' apresentaram maior potencial per se quanto ao rendimento de grãos. O topcross Branco Oito Carreiras x 'BRS Planalto' apresentou melhor desempenho quanto a número de grãos por fileira, massa de grãos da espiga e diâmetro de espiga, enquanto o Criolão x 'BRS Planalto' apresentou melhor desempenho quanto a número de grãos por fileira e comprimento de espiga. As maiores estimativas de distância genética não implicaram, necessariamente, altos valores de heterose, e tiveram correlação apenas com o comprimento da espiga. Portanto, não é possível predizer os efeitos de alta heterose sobre o rendimento de grãos, com base na distância genética entre as populações envolvidas nos cruzamentos.

Termos para indexação: *Zea mays*, dissimilaridade genética, heterose, populações crioulas, topcross.

Introduction

Corn breeding programs would greatly benefit from a more comprehensive knowledge of Brazilian corn germplasm, since there is evidence of a great competitiveness in the market for the development of new cultivars (Araújo & Nass, 2002). Competition assays and germplasm characterization trials represent the majority of studies on corn landrace in Brazil (Paixão et al., 2008; Carpentieri-Pípolo et al., 2010; Coimbra et al., 2010) show great landrace potential, showing similar, or even greater, performance of landraces, in comparison to commercial and hybrid varieties, especially at low-technology cultivation levels.

Heterosis effects on grain yield are commonly sought (Allard, 1971) because they have a great influence on the success of corn hybrids. According to quantitative genetics, the heterosis effects are related to allele frequency in the parents, and the genetic divergence between such parents positively affects them (Falconer & Mackay, 1996).

Multivariate analysis, such as genetic dissimilarity, are often used to classify genotypes into heterotic groups (Baretta et al., 2016). According to Sudré et al. (2005), studies on genetic dissimilarity are of great importance for breeding programs involving hybridizations, as they provide parameters for the identification of parents that would supply the progeny with greater heterotic effects. The relationship between genetic dissimilarity of landrace populations and heterosis estimates is still poorly studied. The absence of this information has made it difficult to form heterotic groups suitable for the formation of intervarietal hybrids or for the selection of inbred lines in breeding programs (Baretta et al., 2017; Carvalho et al., 2017).

The objective of this work was to evaluate the performance of some intervarietal hybrids, from topcross crosses between corn landrace populations and a broad genetic-based tester, as well as to verify whether the genetic dissimilarity between the populations is correlated with heterosis of the intervarietal hybrids in the field.

Materials and Methods

The experiment was carried out in the Centro Agropecuário da Palma (31º45'S, 52º29'W, at 13 m altitude), in an experimental area belonging to the Universidade Federal de Pelotas, in the municipality of Capão do Leão, in the state of Rio Grande do Sul, Brazil, on an Argissolo Vermelho-Amarelo distrófico, according to Santos et al. (2006), i.e., a Paleudalf soil.

In the 2012/2013 crop season, nine topcross hybrids, obtained from crosses between the 'BRS Planalto' tester and landrace populations were evaluated: Argentino Branco × 'BRS Planalto', Dente de Ouro × 'BRS Planalto', Amarelão × 'BRS Planalto', Criolão × 'BRS Planalto', Caiano Rajado × 'BRS Planalto', Branco Oito Carreiras × 'BRS Planalto', Branco Roxo Índio × 'BRS Planalto', Cateto Branco × 'BRS Planalto', and Argentino Amarelo × 'BRS Planalto'. The landrace populations were evaluated with the top crosses in the 2013/2014 crop season.

A randomized complete block design, with three replicates, was used. The experimental plots consisted of two 5.0 m rows, with 42 plants per plot (with 0.70 m spacing between rows), corresponding to the density of 60,000 plants ha^{-1}. Cultural traits were performed in accordance with the recommendations for the culture in the region.

The following traits were evaluated: leaf angle (LA), obtained with the first leaf below the first ear, in three plants; number of tassel branches (NT); height of ear insertion (EH); plant height (PH) from soil surface up to the last leaf node of the plant; ear diameter (ED), measured in the central part of three ears; number of grains per ear (NG); number of grain per row (NGR); grain mass per ear (GM); ear mass (EM); ear length (EL); prolificacy (PROL), which refers to the relation between total of ears per total of plants in the plot; 100-grain mass (HGM); and grain yield (GY) per plot, corrected to 13% moisture.

Data were subjected to the analysis of variance for the genitor populations and their topcross hybrids. Heterosis estimates were performed based on the model (Falconer & Mackay 1996).

The genetic dissimilarity between the genitor populations was estimated using the generalized distance of Mahalanobis (D^2), with data from the means of the genotypes and the residual covariance matrix, according to Cruz et al. (2012). The UPGMA grouping method was used to form the dendrogram. In order to verify the fit between the dissimilarity matrix and the dendrogram, the cophenetic correlation coefficient (r) (Sokal & Rohlf, 1962) was calculated with the NTSYS program (Rohlf, 2000). The Pearson's correlation coefficient between genetic dissimilarity and heterosis estimates was evaluated for the different characters, using the SAS version 9.3 software (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

The individual mean squares for populations and topcross hybrids differed significantly for most of the characters, except ear height, for populations, and grains number, ear diameter, and ear length for top cross hybrids. The landrace populations significantly interacted with their topcross hybrids as to NG, ED, NGR, GM, EM, EL, and GY (Table 1). Machado et al. (2008) mention that crosses between landrace varieties and improved cultivars are an important strategy for the conservation of genetic variability in corn, as well as for obtaining new varieties.

The variation amplitude between the highest and lowest values verified in all evaluated characters evidenced a strong dispersion in the data, which is indicative of the existence of a great genetic variability between the populations and in their topcross hybrids. The variation verified in the landrace populations allows of the possibility of identification of parents that, when combined, would show a greater or lower hybrid vigor (Table 1). Greater amplitudes were observed in the topcross hybrids than in the genitor populations, for most of the characters: NG, PH, ED, NGR, GM, EM, and GY. This result indicates the presence of complementary genes distributed among the parents, which are potentially able to maximize responses in the F_1 generation, as reported by Bertan et al. (2009). Genetic diversity studies provides an opportunity for the identification of varieties with high-combining capacity, which can assist breeding programs in benefiting from heterosis (Machado et al., 2008).

The landraces Amarelão and Branco Oito Carreiras and the topcross Branco Roxo Indio x 'BRS Planalto' stood out for HGM standard deviations that were higher than the average for this trait (Table 2). Dente de Ouro population and the topcrosses Branco Oito Carreiras x 'BRS Planalto' and Criolão x 'BRS Planalto' had the highest values for NGR; and the topcross Branco Oito Carreiras x 'BRS Planalto' showed the highest values for GM. 'Dente de Ouro' x 'BRS Planalto' stood out with the highest NG means. These variables are commonly

Table 1. Analysis of variance of nine landrace populations of corn (*Zea mays*) and their topcrosses with the 'BRS Planalto' tester.

Source of variation	DF	Evaluated trait[(1)]												
		NG	LA	HGM	NTB	EH	PH	ED	NGR	GM	EM	PROL	EL	GY
Population (P)	8	13,635.80**	53.03*	133.01**	19.74**	916.25	1,697.09**	39.35**	24.16**	19,245.64**	27,822.72**	0.11**	10.02**	9.44**
Topcross (T)	8	2,383.35^{ns}	57.70**	19.03**	26.40**	422.38**	1,239.24**	6.43^{ns}	28.62**	4,169.03**	4,044.05**	0.08**	3.45^{ns}	3.06**
P x T	1	103,666.73**	22.48^{ns}	0.01^{ns}	0.22^{ns}	340.26^{ns}	233.29^{ns}	130.64**	180.84**	179,188.99**	198,541.43**	0.03^{ns}	24.74**	41.27**
Residue	50	3,758.25	24.98	28.13	8.70	254.51	571.95	8.95	11.39	4,366.87	6,137.98	0.04	3.17	2.15
Population amplitude and coeficient of variation														
Minimum	-	208.44	22.00	29.13	12.33	86.00	165.67	33.60	26.00	306.85	349.31	0.57	12.17	0.68
Maximum	-	480.00	42.67	53.11	24.00	152.00	267.33	48.34	42.00	573.07	697.03	1.71	21.00	6.78
CV (%)	-	20.70	17.75	16.89	16.82	15.19	10.46	8.48	9.33	19.30	19.54	22.31	11.46	48.11
Topcross amplitude and coeficient of variation														
Minimum	-	362.67	19.67	36.51	12.00	101.67	181.67	42.70	31.67	437.93	534.57	0.79	15.5	2.86
Maximum	-	510.89	40.00	46.62	23.67	148	276.67	51.34	43.67	670.75	779.81	1.56	21.83	7.03
CV (%)	-	9.58	15.68	6.94	17.93	10.27	10.03	4.57	9.11	8.70	7.32	17.12	7.97	19.33

[(1)]LA, leaf angle; HGM, mass of one hundred grains; NTB, number of tassel branches; EH, ear height insertion (cm); PH, plant height (cm); ED, ear diameter (mm); NG, number of grains per ear; NGR, number of grains per ear row; GM, grain mass per ear (g); EM, ear mass (g); PROL, prolificacy; EL, ear length (cm); and GY, grain yield per plot (kg). * and **Significant, by the F test, at 5 and 1% probability, respectively.

DOI: 10.1590/S1678-3921.pab2019.v54.00265

Table 2. Trait means for the nine landrace populations of corn (*Zea mays*), and their nine topcross hybrids with the 'BRS Planalto' tester(1).

Genotype	Means of evaluated trait(2)												
	LA	HGM	NTB	EH	PH	ED	NG	NGR	GM	EM	PROL	EL	GY
						Topcross hybrid							
Argentino Branco x BRS Planalto	30.27	39.79	13.56I	120.78	236.78	44.28	442.96	37.67	474.70	593.14	0.99	17.28	4.68
Branco Roxo Índio x BRS Planalto	28.60	45.91S	13.33I	129.56	236.56	47.63S	405.11	32.06I	532.32	626.41	0.85	17.44	5.66
Amarelão x BRS BRS Planalto	27.27	41.68	18.22	105.78I	222.11	45.94	418.96	37.78	554.16	616.49	1.00	18.90	5.60
Caiano Rajado x BRS Planalto	21.77I	41.26	17.58	136.22	236.67	47.50S	440.00	38.89	522.88	633.95	1.09	19.78	6.15
Argentino Amarelo x BRS Planalto	28.27	40.07	16.56	133.11	240.89	43.65	438.89	36.29	475.56	562.14	1.44S	18.00	3.20
Dente de Ouro x BRS Planalto	36.79S	38.23	23.08S	140.78S	250.45	45.27	504.22S	38.56	541.37	619.51	1.14	18.33	5.06
Cateto Branco x BRS Planalto	25.00	38.68	14.67	112.33	191.78I	45.91	459.26	36.89	533.27	639.61	1.02	19.83	5.29
Branco 8 Carreiras x BRS Planalto	32.78	42.46	16.67	129.00	219.44	45.85	460.30	42.56S	593.97S	691.78S	1.02	19.17	6.22S
Criolão x BRS Planalto	31.33	37.90	17.89	137.00	262.94S	43.72	456.15	41.85S	544.99	656.35	0.96	20.22S	6.56S
						Landrace population							
BRS Planalto (Tester)	27.89	43.60	16.02	111.33	244.25	46.89	474.74	36.22	538.22	645.30	1.17	19.50	6.60S
Argentino Branco	24.89	38.22	14.78	109.29	222.44	39.79I	300.89	31.89I	341.32I	414.25I	1.12	15.50	3.40
Dente de Ouro	33.22	33.07I	18.83S	138.89	263.14S	44.41	405.93	40.10S	483.93	518.93	1.10	16.51	4.37
Amarelão	33.56	50.72S	17.00	134.33	220.11	43.45	250.52I	30.58I	364.22	496.71	0.86	17.09	2.45I
Criolão	25.72	41.28	19.53S	138.49	236.33	41.10	312.66I	33.44	392.87	484.19	0.82I	19.05	4.40
Caiano Rajado	31.67	42.96	16.33	144.00S	247.89	43.91	414.74	35.22	430.22	561.97	1.34S	18.15	1.32I
Branco Oito Carreiras	37.52S	49.22S	15.22	118.11	222.11	44.89	371.63	34.81	511.27	634.32	0.92	19.72	5.09
Cateto Branco	27.23	34.50I	21.55S	92.55I	178.67I	42.81	361.33	32.10I	362.31	427.04I	0.75I	14.45I	1.13I
Argentino Amarelo	32.00	32.63I	13.44I	112.38	225.25	34.50I	344.74	35.22	311.97I	365.24I	0.98	16.78	3.93
Branco Roxo Índio(3)	-	-	-	-	-	-	-		-	-	-	-	-
General average	29.77	40.68	16.90	124.66	230.99	43.97	403.50	36.23	472.75	565.96	1.03	18.09	4.51
Standard deviation	4.99	5.20	2.91	16.09	23.53	3.31	74.67	3.79	87.03	97.78	0.20	1.88	1.68

(1)S, superior, and I, inferior to the general mean + a standard deviation. (2)LA, leaf angle; HGM, mass of one hundred grains; NTB, number of tassel branches; EH, ear height insertion (cm); PH, plant height (cm); ED, ear diameter (mm); NG, number of grains per ear; NGR, number of grains per ear row; GM, grain mass per ear (g); EM, ear mass (g); PROL, prolificacy; EL, ear length (cm); and GY, grain yield per plot (kg). (3)Results compromised by the loss of data on a parental in the trial.

referred to as yield components, which show a high correlation associated with grain yield (Pavan et al., 2011; Khalili et al., 2013; Zeeshan et al., 2013). The topcrosses Branco Roxo Índio x 'BRS Planalto' and Caiano Rajado x 'BRS Planalto' stood out for ED; and Criolão x 'BRS Planalto', for EL. Fancelli & Dourado-Neto (1999) mention that corn breeding programs should consider these traits, as they are positively related to GM. According Nemati et al. (2009), the increase of ear diameter causes an increase in the number of rows per ear, consequently increasing the NG with a positive reflect on grain yield.

The Caiano Rajado population and Argentino Amarelo x 'BRS Planalto' topcross had the highest means for PROL. Prolific plants generally show a greater tolerance to adverse conditions, due to their ability to develop at least one ear, even under stressing conditions, and more than one when the environmental conditions are favorable. PROL is also related to plant capacity in compensating for grain yield loss when plant stands are below the ideal one (Sangoi et al., 2010).

It should be noted that the Cateto Branco population and the topcrosses Amarelão x 'BRS Planalto' and Cateto Branco x 'BRS Planalto' show lower averages for EH and PH. These traits are desirable in maize genotypes because they facilitate harvest and make the plants more resistant to lodging.

As to grain yield, the 'BRS Planalto' tester and the topcrosses Branco Oito Carreiras x 'BRS Planalto' and Criolão x 'BRS Planalto' achieved promising results, showing a favorable gene pool for exploitation, to generate populations with high potential yields.

The estimates of heterosis (H^2) were very variable in the present study (Table 3). Crosses with high heterosis show a high potential for use in breeding programs (Bertan et al., 2009). Caiano Rajado x 'BRS Planalto' (H^2 = 55.3%), Cateto Branco x 'BRS Planalto' (H^2 = 36.9%), Amarelão x 'BRS Planalto' (H^2 = 23.6%), Criolão x 'BRS Planalto' (H^2 = 19.3%), and Branco Oito Carreiras x 'BRS Planalto' (H^2 = 6.47%) had the highest estimates of heterosis for grain yield, and are recommended for promoting productivity in studies with landrace maize populations. Moreover, they have distinct genetic backgrounds, which probably resulted in a high frequency of dominant alleles in the hybrid progenies. Paterniani et al. (2008) also showed a high range of heterosis values when studying a set of 36

Table 3. Heterosis estimates of the evaluated traits[(1)] in nine topcross crosses between landrace corn (*Zea mays*) populations and the 'BRS Planalto' tester.

Topcross	Estimated heterosis (%)												
	LA	HGM	NTB	EH	PH	ED	GN	NGR	GW	EW	PROL	EL	GY
Argentino Branco x BRS Planalto’	14.7	-2.75	-12.0	9.49	1.47	2.16	14.2	10.6	7.94	12.0	-13.8	-1.28	-6.36
Amarelão x BRS Planalto	-11.3	-11.6	10.3	-13.9	-4.34	1.69	15.5	13.1	22.8	7.97	-1.8	3.28	23.6
Caiano Rajado x BRS Planalto	-26.9	-4.66	8.69	6.7	-3.82	4.62	-1.07	8.86	7.98	5.02	-12.8	5.05	55.3
Argentino Amarelo x BRS Planalto	-5.59	5.12	12.4	19	2.62	7.27	7.11	1.59	11.9	11.3	34.5	-0.77	-39.2
Dente de Ouro x BRS Planalto	20.4	-0.26	32.5	12.5	-1.28	-0.83	14.5	1.03	5.93	6.42	0.44	1.81	-7.66
Cateto Branco x BRS Planalto	-9.27	-0.96	-21.6	10.2	-9.31	2.37	9.86	7.98	18.4	19.3	6.43	16.8	36.9
Branco Oito Carreiras x BRS Planalto	0.22	-8.52	6.74	12.4	-5.89	-0.08	8.77	19.8	13.2	8.12	-2.08	-2.27	6.47
Criolão x BRS Planalto	16.9	-10.7	0.65	9.68	9.42	-0.63	15.9	20.2	17.1	16.2	-3.19	4.89	19.3
Branco Roxo Índio x BRS Planalto[(2)]	-	-	-	-	-	-	-	-	-	-	-	-	-
Amplitudes of variation													
Minimum	-26.9	-11.6	-21.6	-13.9	-9.31	-0.83	-1.07	1.03	5.93	5.02	-13.8	-2.27	-39.2
Maximum	20.4	5.12	32.5	19	9.42	7.27	15.9	20.2	22.8	19.3	34.5	16.8	55.3
Mean	-0.11	-4.29	4.72	8.26	-1.39	2.07	10.60	10.40	13.16	10.79	0.96	3.44	11.04

[(1)]LA, leaf angle; HGM, mass of one hundred grains; NTB, number of tassel branches; EH, ear height insertion (cm); PH, plant height (cm); ED, ear diameter (mm); NG, number of grains per ear; NGR, number of grains per ear row; GM, grain mass per ear (g); EM, ear mass (g); PROL, prolificacy; EL, ear length (cm); and GY, grain yield per plot (kg). [(2)]Results compromised by the loss of data on a parental during the trial.

hybrids, confirming the high-genetic variability among the hybrids and the great diversity among parental lines. Hallauer et al. (2010) presented a compilation of heterosis data for grain yield in corn, with of 20.63% heterosis mean values, which is higher than the average estimates observed in the present study. However, Ferreira et al. (2009) report that heterosis was evenly distributed among crosses of landrace populations, and did not observe a differentiated heterotic contribution of each variety, which is in disagreement with our results. These findings corroborate the fact that the heterosis estimates depend on and are directly related to the studied populations.

According to Moreira et al. (2009), the generalized distance of Mahalanobis (D^2) can be used as a powerful tool to estimate the genetic dissimilarity, in order to assist the selection of parents for more promising combinations. For Barili et al. (2011), genotype classifications in heterotic groups can be done with information on genetic dissimilarity. We observed that in the formation of two large groups, according to their genotype mean dissimilarity (Figure 1), the first one was formed by the 'BRS Planalto' tester and the population Branco Oito Carreiras; and the second group, by the populations Argentino Branco, Argentino Amarelo, Caiano Rajado, Dente de Ouro, Amarelão, Criolão, and Cateto Branco.

Heterosis levels were significant and positively correlated only with the genetic distance determined for the ear length trait (Figure 3). However, no significant correlations were observed for the remaining characters, in the investigated populations (Figures 2 and 3). According to Paiva et al. (2002), the combination of genetically distant parents does not always result in expressive heterosis. Paterniani et al. (2008) reported that genetic distances were not correlated with heterosis, and that this trait does not allow inferences on promising crosses in breeding programs. Moreover, these authors reported that higher estimates of genetic dissimilarity did not entail higher values of specific combining ability, and do not correlate with hybrid productivity. Guimarães et al. (2007) investigated the correlation between heterosis estimates and genetic distance between hybrids, determined with molecular markers, and they also observed that the genetic distance does not allow of inferences on the crosses, in corn breeding programs.

The presence of significant associations between heterosis and genetic distance could immensely help the formation of breeding programs, since it allows of previous decision on parents to be used in the crosses (Dias & Resende, 2001). However, these associations are intrinsic to the gene pool under

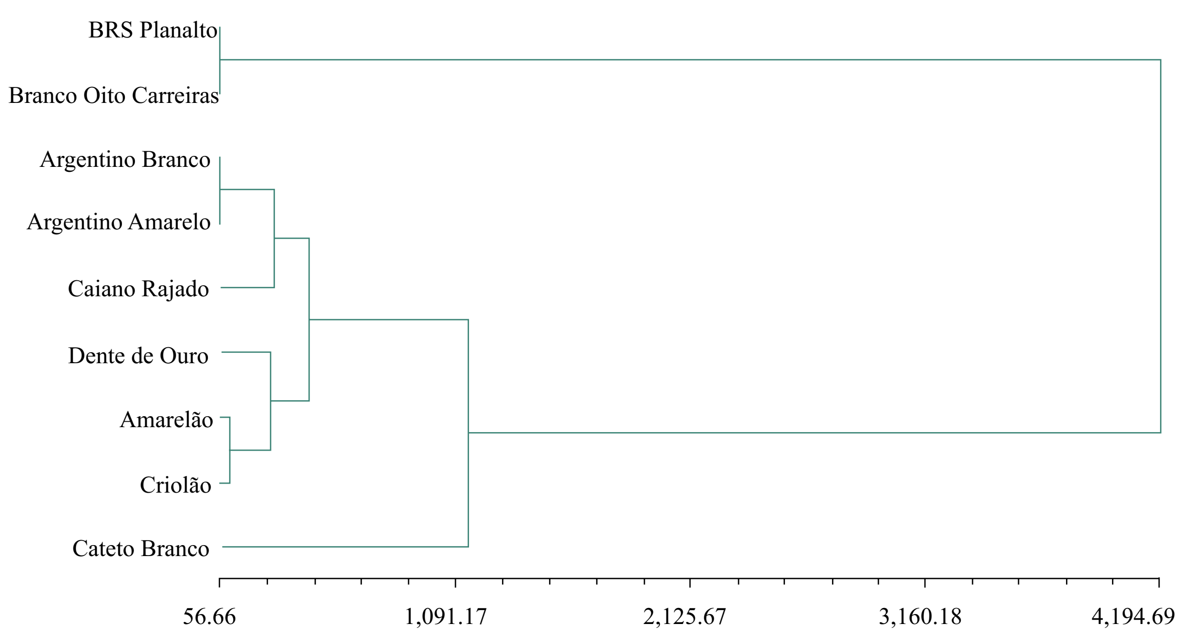

Figure 1. Genetic dissimilarity among the nine corn landrace populations, according to the Mahalanobis generalized distance (D^2), based on the means obtained for 13 traits. Average dissimilarity, 1,972.30; and cophenetic correlation coefficient, 0.85 .

DOI: 10.1590/S1678-3921.pab2019.v54.00265

investigation. It is important to mention, however, that the absence of significant association between heterosis and genetic distance, as observed in the present study, especially for grain yield, may also be related to nonlinearity between the analyzed parameters (Simon et al., 2012).

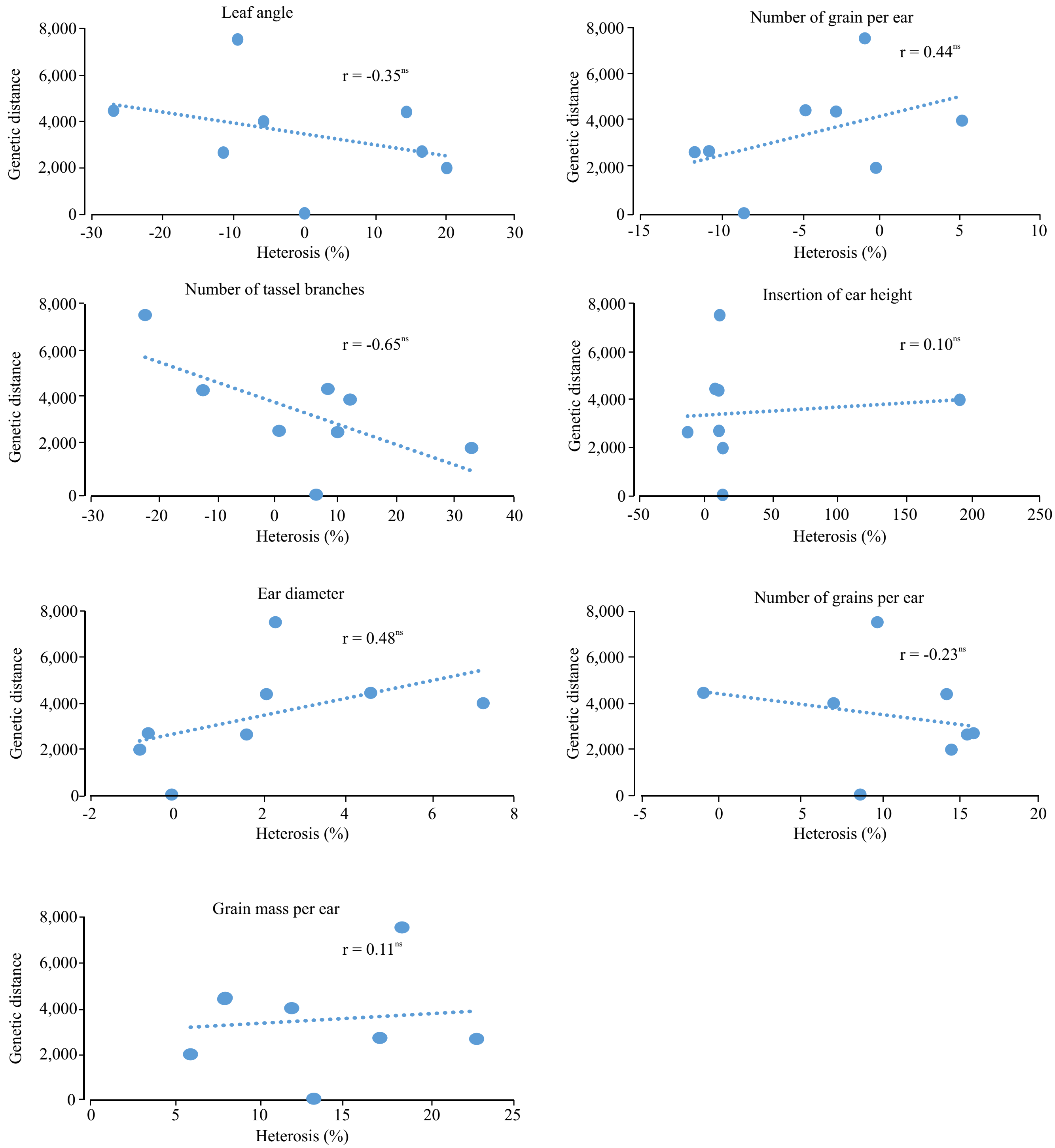

Figure 2. Pearson's correlation coefficient (r) between heterosis, in topcross hybrids, and the genetic distance of the landrace parents. ^{ns}Nonsignificant. *Significant, at 5% probability.

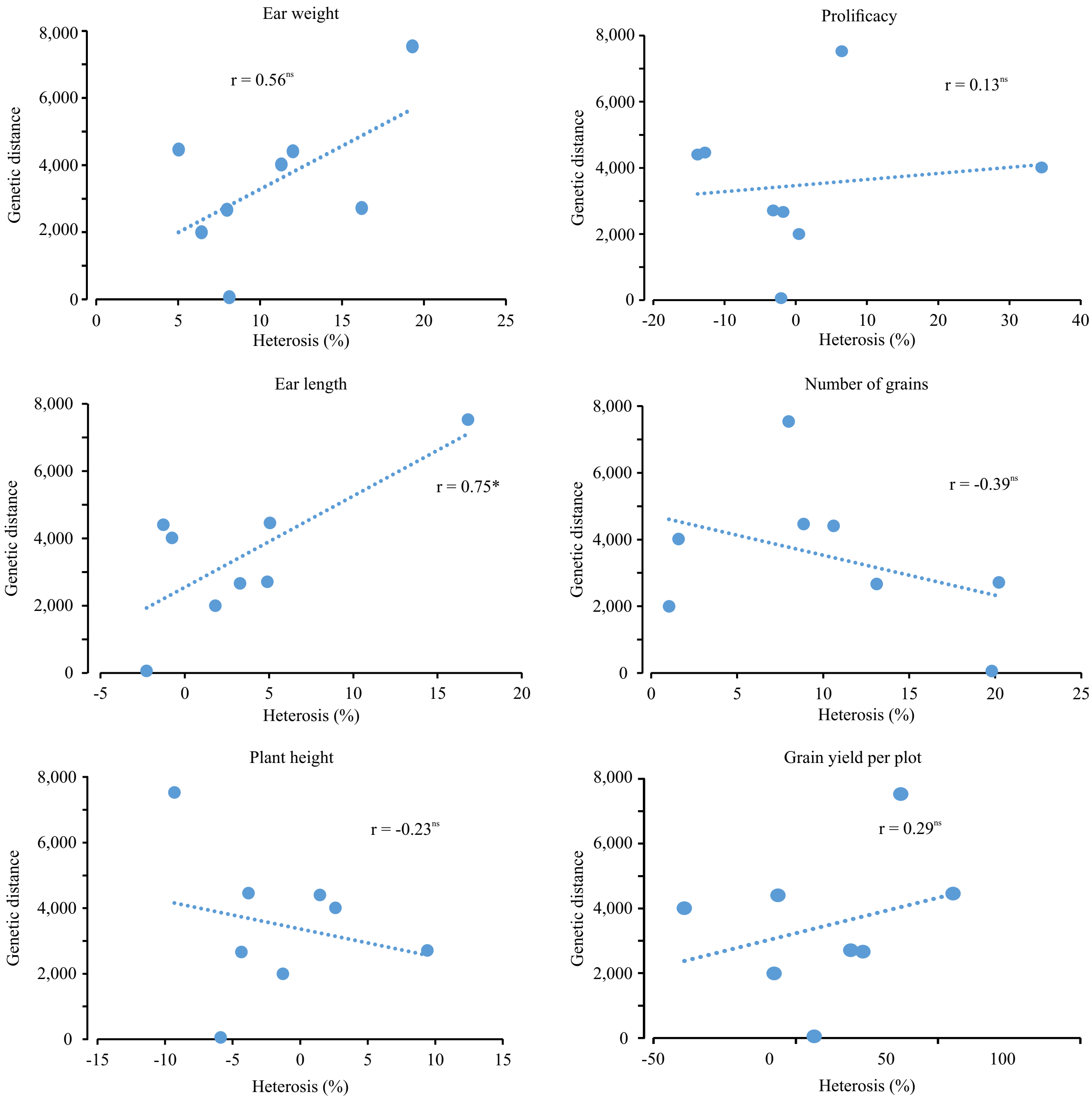

Figure 3. Pearson's correlation coefficient (r) between heterosis, in topcross hybrids, and the genetic distance of the landrace parents. nsNonsignificant. *Significant at 5% probability.

Landrace populations and topcross hybrids with greater per se potential for grain yield were: Branco Oito Carreiras x 'BRS Planalto' and Criolão x 'BRS Planalto'. The first topcross also displays a great performance for grain number per row, grain weight per ear, and ear diameter; and the second one, for grain number per row, and ear length.

Conclusion

Greater genetic distance estimates between the evaluated landrace populations do not necessarily imply high-heterosis values, but their topcrosses with the 'BRS Planalto' tester show new varieties with high agronomic potential.

Acknowledgments

To Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes), to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and to Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (Fapergs), for funding the project and granting the first author's doctoral fellowship.

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