Journal of Agricultural Science; Vol. 10, No. 2; 2018
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Interrelations of Characters and Multivariate Analysis in Corn

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Received: October 23, 2017 Accepted: December 20, 2017 Online Published: January 15, 2018

doi:10.5539/jas.v10n2p187 URL: https://doi.org/10.5539/jas.v10n2p187

Abstract

The objective of this work was to evaluate the agronomic performance of corn hybrids, the interrelations of the characters with the grain yield, and to genetically discriminate the corn hybrids by means of the dispersion analysis of the canonical variables. The experiment was conducted in the agricultural crop of 2013/2014, in an area belonging to the Federal University of Santa Maria, Campus of Frederico Westphalen, RS. The experimental design was a randomized block design, with four replications. The treatments were composed of seven maize hybrids with different genetic bases and maturation cycles. The LG 6304 modified simple hybrid has higher grain yield than the others. The characters plant height, spike insertion height and number of grains per row of spike have positive interrelations with grain yield of corn hybrids. Hybrids are not grouped according to the genetic basis and maturation cycle. The canonical variables explain 94.62% of the existing genetic variation, and allows the formation of five groups of maize hybrids.

Keywords: *Zea mays* L., track analysis, canonical variables

1. Introduction

Corn (*Zea mays* L.) is considered one of the main cereals cultivated worldwide. It is a raw material for many products destined to human and animal feeding, because the grains are a source of carbohydrates, proteins and lipids (Fancelli & Dourado Neto, 2004; Carvalho et al., 2013; Pelegrin et al., 2016). This cereal is presented as the second crop with greater emphasis on the national agricultural scenario, being cultivated from small farms for subsistence agriculture, to farmers with high levels of technological management (Sangoi et al., 2010). The expansion of corn production has increased over the years due to population growth, food needs, and the production of biofuels (Silva, 2004; Carvalho et al., 2014).

The productive performance of corn hybrids is closely related to biotic and abiotic effects. These, together, influence the magnitude of the relationships of the characters of agronomic importance, and reflect on the productive potential of corn (Brachtvogel et al., 2009; Baretta et al., 2015). It is important to understand which traits are associated with crop yield and to determine which traits are important and should be measured in corn hybrids trials. In this way, the track analysis developed by Wright (1921) is used to unfold the linear correlations in direct and indirect effects of the traits on the dependent character (Cruz, 2012; Souza et al., 2015a).

The efficient interpretation of the results is evidenced in conjunction with the multivariate analyzes, highlighting the canonical variables that allow the identification of more similar or distant genotypes, demonstrating these differentiations by graphically applied scores (Cruz, 2012; Souza et al., 2015b). This analysis provides greater efficiency in distinguishing genetic variation among genotypes, as established by standardized observations, and the residual effects of genotypes (Cruz, 2014). Therefore, the objective of this work was to evaluate the agronomic performance of corn hybrids, the interrelations of the characters with grain yield, and to genetically discriminate corn hybrids by means of dispersion analysis of canonical variables.

2. Material and Methods

The experiment was conducted in the agricultural crop of 2013/2014, in an area belonging to the Federal University of Santa Maria, Campus of Frederico Westphalen, RS. Soil is classified as dystrophic red Latosol, and the climate is characterized by Köppen as subtropical Cfa, and the geographic coordinates correspond to 27°39′56″ S and 53°42′94″ W, with an altitude of 490 meters and an annual rainfall of 1,800 mm (MALUF, 2000).

The experimental design was a randomized block design, with four replications. The treatments were composed of seven corn hybrids with different genetic bases and maturation cycles (Table 1), totaling 28 experimental units.

Table 1. Description of the hybrids used in the experiment and their characteristics regarding the type of crossing and maturation cycle

Corn Hybrids	Genetic Basis	Maturation cycle
PL 6880	Triple hybrid	Normal
LG 6050	Simple hybrid	Early
LG 6304	Modified simple hybrid	Super early
SG 6302	Triple hybrid	Super early
LG 6033	Simple hybrid	Early
SG 6418	Triple hybrid	Early
SG 6011	Modified simple hybrid	Super early

The experimental units were composed of four sowing rows, five meters (m) in length, and spaced 0.7 m apart. The implementation of the experiment was based on the direct seeding system, with a population density of 70,000 ha^{-1} plants. The fertilization of 300 kg ha^{-1} of NPK in the formulation 05-20-20 was applied, and 180 kg ha^{-1} of nitrogen in the amide form was applied for top dressing, on the stages V4 and V6, following the phenological scale proposed by (Ritchie et al., 1993). The control of invasive plants, insect-pests, and diseases were carried out in a preventive way in order to minimize biotic influences in the experiment (Nardino et al., 2016a).

The determination of characters of agronomic interest was based on the methodology proposed by Carvalho et al. (2014), where ten plants per experimental unit were randomly sampled, and the measured characters were: plant height (PH), results in meters (m); height of spike insertion (HSI), results in m; spike diameter (SD), results in millimeters (mm); spike lenght (SL), results in cm; spike mass (SM), results in grams (g); number of grain rows of the spike (NGS), results in units; number of grains per row of spike (NGR), results in units;cob diameter (CD), results in mm; cob mass (CM), results in g; spike grain mass (SGM), results in g; mass of one thousand grains (MTG), results expressed in g; prolificacy (PRO), results in units; grain yield (GY), results in bags per hectare (sc ha^{-1}).

The obtained data were submitted to analysis of variance by the F test at 5% of error probability, where their assumptions were verified, after the multiple comparison of means by the Tukey test was performed. The characters under study comprised a matrix of linear phenotypic correlations, being submitted to the multicollinearity diagnosis by the number of conditions (NC) of the matrix. Subsequently, the analysis of the trail with multicollinearity was established, establishing the grain yield as dependent, and the other characters as explanatory (Cruz et al., 2012). The analysis of canonical variables was performed according to (Cruz et al., 2012). Statistical analyzes were performed using the statistical software Genes (Cruz, 2013).

3. Results and Discussion

The analysis of variance revealed significant ($p \leq 0.05$) for the characters, plant height (PH), height of spike insertion (HSI), number of grains per row (NGR), cob diameter (CD) and grain yield (GY). No significance was observed for the trait spike diameter (SD), spike length (SL), spike mass (SM), number of grain rows of the spike (NGS), cob mass (CM), spike grain mass (SGM), mass of one thousand grains (MTG) and prolificacy (PRO).

For the plant height character (PH) the hybrids PL 6880, LG 6050 and LG 6304 were superior to the others (Table 2). The magnitude of this variable is the result of genotype vs. cultivation environment and management systems (Dourado Neto et al., 2003). In contrast, the hybrid SG 6011 reveals inferiority for this character. Hybrids with smaller stature tend to have less lodging and broken plants, with no detrimental effects on the productive potential of the genotype (Sawazaki & Paterniani, 2004).

Table 2. Average results for the variables, plant height (PH), height of spike insertion (HSI), number of grains per row (NGR), cob diameter (CD) and grain yield (GY)

Corn hybrids	PH (m)	HSI (m)	NGR (un)	CD (mm)	GY (sc ha^{-1})
PL 6880	3.22 a	1.95 a	39.44 a	26.61 b	132.6 c
LG 6050	3.05 ab	1.7 ab	34.22 ab	27.67 ab	158.7 abc
LG 6304	2.93 abc	1.59 abc	31.22 ab	26.20 b	182.5 a
SG 6302	2.77 bcd	1.39 bc	33.11 ab	28.31 ab	166.1 abc
LG 6033	2.71 cd	1.44 bc	39.22 a	26.03 b	174.7 ab
SG 6418	2.68 cd	1.55 abc	37.22 ab	29.46 ab	154.4 abc
SG 6011	2.64 d	1.28 c	29.66 b	30.38 a	141.7 bc
CV (%)	3.58	9.17	9.16	4.70	8.47

Note. * Averages followed by the same lowercase letter in the column do not statistically differ for Tukey with 5% of error probability.

For the height of spike insertion (HSI), the hybrids PL 6880, LG 6050, LG 6304 and SG 6418 are superior, in contrast, the hybrid SG 6011 revealed the smaller stature among the genotypes (Table 2). This character is of extreme importance for the crop, since it is determinant for the best balance of the plant (Kappes et al., 2011; Nardino et al., 2016b). Research has shown that this characteristic can be influenced by the intraspecific competition of plants per unit area (Kappes et al., 2011; Nardino et al., 2016c), high levels of nitrogen fertilizers (Santos et al., 2010), potassic fertilizers (Rodrigues et al., 2014), and characteristics of the genotype used (Meira, 2006). Studies have determined that 83% of modern corn genotypes show a height of spike insertion of around 1.3 m (Sawazaki & Paterniani, 2004).

The number of grains per row of spike (NGR) showed similar results for hybrids PL 6880, LG 6050, LG 6304, SG 6302, LG 6033, SG 6418, and higher than SG 6011 (Table 2). NGR is related to the length of the spike, being this genetically influenced, and mainly by genotype × environment interaction (Vilela et al., 2012). Hybrids that present smaller NGR have spikes with smaller dimensions in length, can compromise the yield of grains. The influence of the growing environment on the determination of the characteristics related to the spike, such as number of rows of grains and number of grains per row is decisive in the phenological stages between V4 and V9, during which period these yield components are defined (Vilela et al., 2012).

The cob diameter (CD) is shown to be superior for the hybrids SG 6011, SG6418, SG6302, LG6050 (Table 2). The high magnitude of this character can characterize the low efficiency of the genotype in partitioning its assimilates, since it destines them to the growth of a nonproductive morphological structure, where it increases its dimensions. Therefore, hybrids are sought with less evidence of this character so that the assimilates are more efficiently used in the grain filling. Research has shown that greater diameters of cob can be derived from periods of energy deficit by the plant, through the remobilization of photoassimilates to drains, where they do not contribute to the genotype productivity (Carvalho et al., 2014). Studies observed that the size of the cob can be influenced by the population density (Kappes et al., 2011), environmental conditions (Carmo et al., 2012; Monteiro et al., 2016), phosphate (Figueiredo et al., 2012) and nitrogen fertilizers (Kappes et al., 2009; Demari et al., 2016).

Grain yield (GY) is higher for the LG 6304 hybrid with 182.50 sc ha^{-1}, and a low yield is evidenced for the PL 6800 hybrid with 132.6 5 sc ha^{-1} (Table 2). In this study, it is observed 49,9 sc ha^{-1} of differences between the most and least productive hybrid, where it is evidenced that the LG 6304 modified simple hybrid presents higher yield when compared to the triple hybrid PL 6800, under these conditions the type of crossing to obtain the hybrid is crucial to define being productive potential. Researches determine that the differential results are derived from the genetic characteristics of the hybrids, and climatic conditions of the growing environment (Cardoso et al., 2004). Studies have determined that efficient selection of genotype with high genetic potential can influence up to 50% in grain yield (Cruz et al., 2012).

The multicollinearity diagnosis of the matrix of linear phenotypic correlations revealed a condition number (NC) of 18.40 and was considered of low collinearity without serious problems in the matrix. In this way, track analysis was performed, neglecting the effects of multicollinearity. The phenotypic track analysis was performed for the seven corn hybrids grown in the 2013/2014 crop season, where the grain yield was determined as dependent, and the characters; plant height (PH), height of spike insertion (HSI), number of grains per row of spike (NGR) and cob diameter (CD), were considered as explanatory. The correlation coefficients were based as follows;nulls (r = 0.00), low or weak (r = 0.00 to r = 0.30), intermediate (r = 0.30 at r = 0.60), high or strong (r = 0.60 at r = 1.00), according to Carvalho et al. (2004).

Plant height (PH) shows a direct intermediate and positive grain yield effect (Table 3), indirect low and positive height of spike insertion (HSI). The total correlation is high and positive (r = 0.60) and proves the direct effects obtained. Plants with larger stature tend to show increase in the height of the spike insertion, providing a modification of the leaf architecture, and increment of leaves per plant, this dynamics together results in increases in the photosynthetic rate and the production of photoassimilates that in the reproductive period will be directed to the grain filling (Argenta et al., 2001; Olivoto et al., 2016).

Table 3. Direct and indirect effects of phenotypic characters; plant height (PA), height of spike insertion (HSI), number of grains per row (NGR), cob diameter (CD), for the grain yield dependent character (GY), measured in seven hybrids of corn

Effects	**PH**	**HSI**	**NGR**	**CD**
Direct to GY	0.451	0.119	0.339	-0.193
Indirect via PH		0.415	0.053	0.16
Indirect via HIS	0.109		-0.003	0.022
Indirect via NGR	0.039	-0.111		0.102
Indirect via CD	-0.068	-0.036	-0.058	
Total	0.600	0.504	0.381	0.063
Coefficient of detemination	0.848			
Residual variable effect	0.142			

The height of spike insertion (HSI) has a direct low and positive effect on the yield of grains, indirectly observed an intermediate and positive effect with plant height (PH), and low and negative with number of grains per row of spike (NGR). The total correlation reveals (r = 0.50) intermediate and positive. The phenotypic associations determine that plants with higher height of spike insertion are higher, in contrast, reduce the dimensions of the spikes through the smaller number of grains per row. The results obtained for PH and HSI are in agreement with that observed by Bello et al. (2010), where they showed direct effects of these characters on grain yield with magnitudes and similar meanings of 0,314 and 0,176, respectively.

The number of grain rows of the spike (NGS) has an intermediate and positive direct effect on grain yield. No pronounced indirect effects are observed in this situation, and the total correlation is intermediate and positive (r = 0.38), where magnitude and sense prove the direct effects to the dependent character. Research has shown that the number of grains per row is determinant to increase productivity in corn (Balbinot Júnior et al., 2012). However, its magnitude is highly influenced by genetic constitution, G×E interaction and population management systems (Dourado Neto et al., 2003; Baretta et al., 2016).

The cob diameter (CD) showed direct spurious effects on grain yield. On the other hand, low and positive indirect effects were obtained with plant height and number of grains per row of the spike (NGR). The total correlation presents (r = 0.06) null, this fact does not result in absence of association among the characters, but the linearity of the data obtained for the cob diameter. Studies reveal that the diameter of the cob had positive relation with the characters related to the size of the spike, such as; number of grain rows of the spike, mass of the spike and mass of grain per spike (Lopes et al., 2007).

The analysis of the canonical variables was determined by the traits, plant height, height of spike insertion, number of grains per row, cob diameter, and grain yield determined in seven corn hybrids cultivated in the

2013/2014 crop season. The genetic variation of corn hybrids was expressed through the first two canonical variables, where VC1 is responsible for 81.85% and VC2 comprises 12.77% of all genetic variation.

In Figure 1 it is possible to visualize the graphically expressed scores by means of the canonical variables VC1 and VC2, being possible to visualize the formation of four groups. In this way, the first group consists of the hybrids 1: (SG 6418), 4: (LG 6050) and 7: (LG 6304) being characterized as, triple, simple and modified, respectively; the second group composed of the hybrid 6: (LG 6033) being a simple hybrid; the third group composed of the hybrid 2: (PL 6880) being a triple hybrid; fourth group: formed by hybrid 3: (SG 6302) being a triple hybrid; and the fifth group consisting of 5: (SG 6011) being a modified simple hybrid.

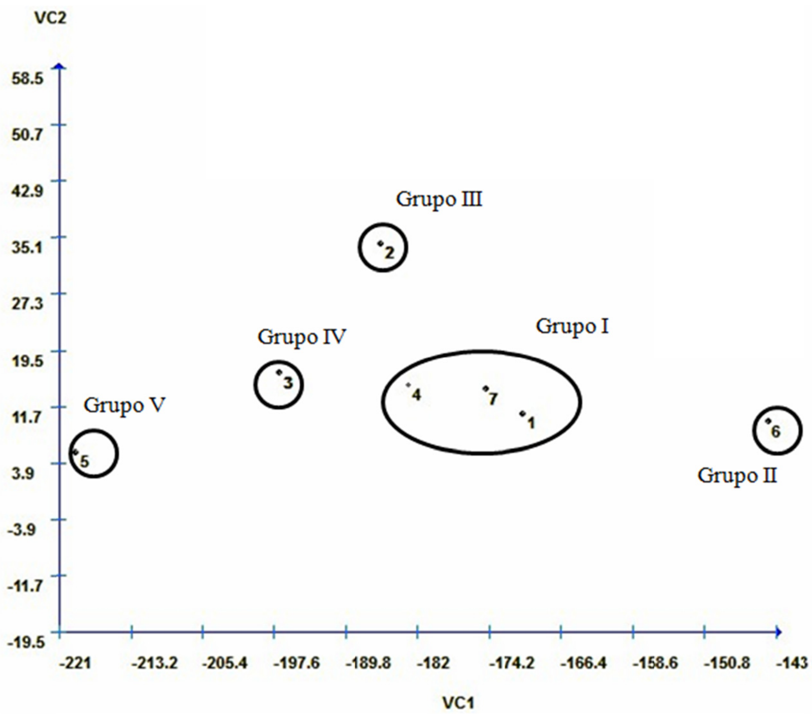

Figure 1. Graphic dispersion of the scores obtained by the analysis of the canonical variables VC1 (81.85%) and VC2 (12.77%) obtained in seven hybrids of corn, being: 1 = (SG 6418); 2 = (PL 6880); 3 = (SG 6302); 4 = (LG 6050); 5 = (SG 6011); 6 = (LG 6033); and 7 = (LG 6304) measured in the agricultural crop 2013/2014

The canonical variables obtained explain 94.62% of the genetic variation involved in the study, so the reliable interpretation of this multivariate analysis should be based on minimum estimates of 80% through the set of characters (Cruz et al., 2006). Therefore, to identify which hybrids of corn are superior in a competition assay, it becomes feasible to use univariate and multivariate analyzes together, which results in adequate responses as to which hybrids are superior, genetically closer, and determine the characters of interest to grain yield in corn.

4. Conclusions

The modified simple corn hybrid LG 6304 has higher grain yield than the other hybrids.

The characters plant height, height of spike insertion and number of grains per row of spike have positive interrelations with grain yield of corn hybrids.

Hybrids are not grouped according to the genetic basis and maturation cycle. The canonical variables explain 94.62% of the existing genetic variation, and allows the formation of five groups of corn hybrids.

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