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Genetic divergence in maize regarding grain yield and tassel traits[1]

Divergência genética de milho em relação à produtividade de grãos e caracteres de pendão

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ABSTRACT – Maize tassels with a longer length and higher number of branches prevent the passage of solar radiation into the upper plant canopy and act as a drain for photoassimilates that could be used for grain production. This study aimed to verify if there is genetic divergence regarding grain yield and tassel traits among maize cultivars in three agricultural years. Twenty maize cultivars were evaluated and 11 tassel traits and grain yield were measured. Individual and joint analyses of variance were performed for each trait. Principal component analysis was performed, the generalized Mahalanobis distance matrix between cultivars was determined, and the genetic divergence analysis was performed, using the unweighted pair group method with arithmetic mean (UPGMA), which allowed constructing the dendrogram. The cophenetic correlation coefficient was calculated to validate the cluster. There is genetic divergence among maize cultivars and six groups of cultivars were formed. Tassel length, total branches number, central spike dry matter, and grain yield are the traits that most contribute to the genetic divergence among maize cultivars.

Key words: Principal components. Genetic dissimilarity. *Zea mays* L.

RESUMO – Pendões de milho, com maior comprimento e maior número de ramificações impedem a passagem da radiação solar para o dossel superior da planta e atuam como dreno de fotoassimilados, sendo que, poderiam ser destinados a produção de grãos. O objetivo deste trabalho foi verificar se há divergência genética, em relação à produtividade de grãos e os caracteres de pendão entre os cultivares de milho, em três anos agrícolas. Foram avaliados 20 cultivares de milho e mensurados 11 caracteres de pendão e a produtividade de grãos. Para cada caractere, foram realizadas as análises de variância individual e conjunta. Foi realizada a análise de componentes principais, determinada a matriz da distância generalizada de Mahalanobis entre os cultivares e realizada a análise de divergência genética, por meio do método de agrupamento da ligação média entre grupo (UPGMA) e, a partir disso, foi construído o dendrograma. Para validação do agrupamento calculou-se o coeficiente de correlação cofenética. Existe divergência genética entre os cultivares de milho e foram formados seis grupos de cultivares. O comprimento do pendão, o número total de ramificações, a massa de matéria seca da espiga central e a produtividade de grãos são os caracteres que mais contribuem para a divergência genética entre os cultivares de milho.

Palavras-chave: Componentes principais. Dissimilaridade genética. *Zea mays* L.

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INTRODUCTION

Maize (*Zea mays* L.) is a monoecious species, that is, it presents female and male inflorescences on the same plant. The female inflorescence, represented by the spike, produces egg cells that turn into grains after fertilization. Tassel is the male reproductive organ and is responsible for producing pollen (BORÉM; GALVÃO; PIMENTEL, 2015). The development of productive lines and hybrids is important in maize breeding programs. Plants with smaller tassels (length) and fewer branches, but with sufficient pollen production for fertilization (DUVICK, 2005; FISCHER; EDMEADES, 2010) are targeted. According to Edwards (2011), longer tassels prevent the passage of solar radiation into the plant canopy and act as a drain for photoassimilates that could be used for grain production.

The genetic divergence is a strategy to obtain selection gains in crosses of divergent groups that have traits of interest. It can be estimated by multivariate analysis techniques, including principal component analysis and dissimilarity measures. The principal component analysis allows discarding traits that contribute little to the discrimination of the evaluated material, thus reducing time, cost, and labor. On the contrary, dissimilarity measures quantify the distances between genotypes, with the generalized Mahalanobis distance being used for data obtained with repetitions, considering the correlations between traits (CRUZ; REGAZZI; CARNEIRO, 2012).

There are several clustering methods, and hierarchical and optimization methods are the most used. In hierarchical methods, parents are grouped by a process repeated at various levels until the dendrogram establishment (CRUZ; CARNEIRO; REGAZZI, 2014). The unweighted pair group method with arithmetic mean (UPGMA) is among the hierarchical methods for clustering analysis and has been used in genetic divergence studies in maize (SIMON *et al.*, 2012), being considered the most efficient method to group maize cultivars (CARGNELUTTI FILHO; GUADAGNIN, 2011).

Studies on genetic divergence through multivariate statistics was carried out in maize by Alves *et al.* (2015), Brewbaker (2015), Cargnelutti Filho and Guadagnin (2011), Chandel and Guleria (2019), Iqbal, Shinwari and Rabbani (2015), Nardino *et al.* (2016, 2017), Oliboni *et al.* (2012), Öner (2018), Silva *et al.* (2016), and Simon *et al.* (2012). However, studies on the genetic divergence between maize cultivars as a function of grain yield and with a higher number of tassel traits, that is, a higher detail between the constituent parts of the tassel, were not found in the literature. This information is of paramount importance, as it allows evaluating the behavior of cultivars to indicate genotypes that present divergent behavior. Thus, this study aimed to verify if there is genetic divergence regarding grain yield and tassel traits among maize cultivars in three agricultural years.

MATERIAL AND METHODS

Twenty maize cultivars (20A55, 30F53, AG8780, BM3066, DKB290, MS2010, MS2013, MS3022, StatusVIP, SX7331, 30A68, AG9025, AM9724, AS1666, AS1677, Celeron, DKB230, P1630, P2530, and SHS7915) were evaluated in three experiments conducted at the experimental area of the Department of Plant Science of the Federal University of Santa Maria, Rio Grande do Sul, Brazil, in the 2015/2016 (experiment 1), 2016/2017 (experiment 2), and 2017/2018 agricultural years (experiment 3) (Table 1). According to the Köppen classification, the regional climate is Cfa, that is, a humid subtropical climate with hot summers and no defined dry season (ALVARES *et al.*, 2013). The soil of the experimental area is classified as an arenic dystrophic Red Argisol (SANTOS *et al.*, 2018).

The experiments were conducted in a randomized complete block design with three replications. The plots consisted of two rows of 5 m in length, spaced 0.80 m between rows and 0.20 m between plants in the row. Plant density was adjusted through manual thinning to reach five plants per meter of row, totaling 62,500 plants ha^{-1}. The cultural practices were carried out according to the recommendations for maize cultivation, keeping the experiment free of weeds, pests, and diseases (FANCELLI; DOURADO NETO, 2009).

A total of 20, 11, and 20 tassels were randomly collected per plot in experiments 1, 2, and 3, respectively, at the end of the reproductive stage. These tassels were identified, stored in paper packaging, and taken to a forced-air oven at 60 °C until reaching a constant weight.

The following traits were measured in each tassel: peduncle length (PL, considering the distance between the collar of the flag leaf and the first branch, in cm), branch space length (BSL, cm), central spike length (CSL, cm), tassel length (TL=PL+BSL+CSL, cm), number of primary branches (NPB), number of secondary branches (NSB), total branches number (TBN=NPB+NSB), peduncle dry matter (PDM, considering the region between the flag leaf collar and the first branch, in g), branch space dry matter (BSDM, g), central spike dry matter (CSDM, g), and total tassel dry matter (TDM=PDM+BSDM+CSDM, g) (Figure 1). Grain yield (GY, Mg ha^{-1} at 13% moisture) was evaluated from all plants in the plot.

The data from the 12 traits were subjected to individual and joint analyses of variance. The cultivar effect was considered fixed, while the agricultural

Table 1 – Descriptors of 20 maize cultivars regarding technology, company, type, cycle, use, grain, color, and investment

Hybrid	Version	Technology	Company	Type[1]	Cycle[2]	Use[3]	Grain[4]	Color[5]	Investment
20A55	PW	PowerCore	Morgan Sementes	TH	E	G/S	SH	LO	Medium
30F53	YH	Optimum Intrasect	Pioneer	SH	E	G/S	SD	O	High
AG8780	PRO 3	VT PRO 3	Sementes Agroceres	SH	E	G	SD	LO	High
BM3066	PRO2	VT PRO 2	Biomatrix	SH	E	G/S	SD	O	High
DKB 290	PRO 3	VT PRO 3	Dekalb	SH	E	G	SD	LO	High
MS 2010	-	Conventional	Melhoramento Agropastoril	SH	E	G	SD	Y/LO	High
MS 2013	-	Conventional	Melhoramento Agropastoril	SH	E	G	SH	LO	High
MS 3022	-	Conventional	Melhoramento Agropastoril	TH	E	G	H	O	Medium
Status	VIP	Agrisure Viptera	Syngenta Seeds	SH	E	G	H	LO	High
SX7331	VIP	Agrisure Viptera	Syngenta Seeds	SH	E	G	H	O	High
30A68	PW	PowerCore	Morgan Sementes	SH	SE	G	SH	LO	High
AG9025	PRO 3	VT PRO 3	Sementes Agroceres	SH	SE	G	SD	LO	High
AM9724	-	Conventional	Melhoramento Agropastoril	SH	SE	G	D	Y/LO	High
AS1666	PRO 3	VT PRO 3	Agroeste	SH	SE	G	SD	Y/LO	High
AS1677	PRO 3	VT PRO 3	Agroeste	SH	SE	G	SD	LO	High
Celeron	TL	Agrisure TL	Syngenta Seeds	SH	SE	G	H	LO	High
DKB 230	PRO 3	VT PRO 3	Dekalb	SH	SE	G	SD	Y	High
P1630	H	Herculex I	Pioneer	SH	SE	G	SD	LO	High
P2530	-	Conventional	Pioneer	SH	SE	G	SH	O	High
SHS 7915	PRO	YieldGard VT PRO	Santa Helena Sementes	SH	SE	G/S	SD	LO	High

[1] SH: single hybrid; TH: triple hybrid. [2] E: early; SE: super early. [3] G: grains; S: silage. [4] SH: semi-hard; SD: semi-dented; H: hard, D: dented. [5] LO: light orange; O: orange; Y: yellow. Information provided by the Fundação Estadual de Pesquisa Agropecuária (FEPAGRO)

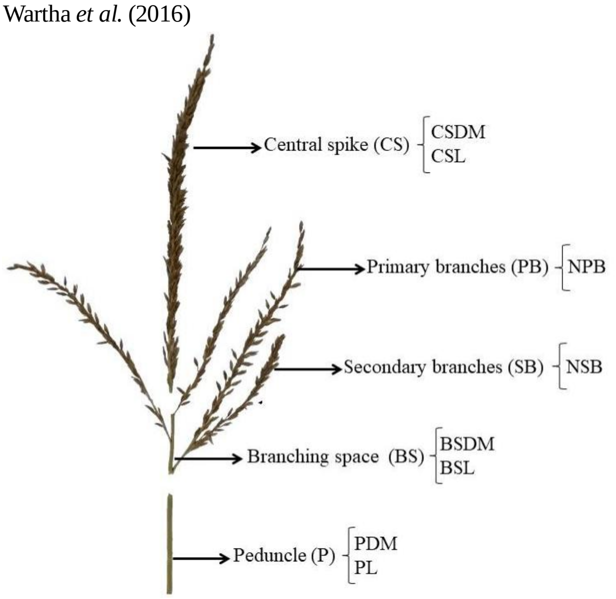
year was considered random in the joint analysis. The differences between the means of the individual analyses of variance were tested using the Scott-Knott test at a 5% significance level for each experiment.

The overall mean obtained in the joint analysis of variance was used to perform the principal component analysis, a statistical technique of multivariate analysis that transforms a set of variables correlated with each other into a smaller set in such a way that their similarities and differences are highlighted (CRUZ; CARNEIRO; REGAZZI, 2014).

Subsequently, the traits were standardized, and the generalized Mahalanobis distance (D^2) matrix was determined. The clustering analysis of the cultivars was performed from D^2 using the hierarchical method unweighted pair group method with arithmetic mean (UPGMA), followed by the construction of the dendrogram (CRUZ; CARNEIRO; REGAZZI, 2014), considering a 50% cutoff point for group formation.

The cophenetic correlation coefficient (CCC) was calculated to evaluate the cluster consistency (FERREIRA, 2018). The CCC allowed verifying the adjustment capacity of the dendrogram in reproducing the dissimilarity matrix. CCC values close to the unit indicate a better representation of the dendrogram (CRUZ; CARNEIRO; REGAZZI, 2014). The cluster

Figure 1 – Representation of the traits evaluated in maize tassels, PL: peduncle length (considering the distance between the collar of the flag leaf and the first branch), in cm; BSL: branching space length, in cm; CSL: central spike length, in cm; NPB: number of primary branches; NSB: number of secondary branches; PDM: peduncle dry matter (considering the region between the flag leaf collar and the first branch), in g; BSDM: branching space dry matter, in g; CSDM: central spike dry matter, in g. Adapted from Wartha *et al.* (2016)



validation was complemented with the analysis of variance to compare the groups of cultivars, and the Scott-Knott test was carried out to compare the means of groups. Statistical analyses were performed using the software Genes (CRUZ, 2016) and the application Office Excel®.

RESULTS AND DISCUSSION

Individual analyses of variance showed that the cultivar effect was significant for the 12 traits in the three agricultural years. The joint analysis of variance enabled to observe significant cultivar effects for all traits, whereas only BSL showed no significant difference for agricultural year. These results show the presence of genetic variability, enabling the identification of superior cultivars. In addition, the interaction cultivar × agricultural year was significant for ten out of the 12 traits, showing the importance of studies on genetic variability in different years of cultivation, as different responses of cultivars can be obtained with changes in the environment (Table 2). According to Cargnelutti Filho *et al.* (2008), clusters of cultivars based on only one growing season may provide misleading information because the environmental variability between years and growing seasons is not considered within the same location. Thus, we can infer that there is genetic variability among maize cultivars, and the results are consistent because they come from three agricultural years, enabling the study of genetic divergence through the UPGMA hierarchical method.

In the joint analysis of variance, the mean tassel length was 46.874 cm, the number of primary branches was 10.161, the total branches number was 12.545, the tassel dry matter was 2.701 g, and the grain yield was 9.184 Mg ha^{-1} (Table 2). Similar results were obtained by Brewbaker (2015), Nardino *et al.* (2016), Simon *et al.* (2012), and *Yi et al.* (2018), respectively, demonstrating an adequate development of maize plants in the three experiments.

The coefficients of variation (CV) ranged from 2.560% for tassel length (experiment 1) to 21.730% for the number of secondary branches (experiment 1) (Table 2). According to the classes established by Pimentel-Gomes (2009) for field experiments with crops, the coefficient of

Table 2 – Significance of the F-test for cultivar (C), agricultural year (Y), interaction C×Y, and mean and coefficient of variation (CV) of the individual and joint analyses of variance of 12 traits evaluated in 20 maize cultivars in the 2015/2016, 2016/2017, and 2017/2018 agricultural years

Trait[(1)]	Experiment	Cultivar (C)	Agricultural year (Y)	C×Y	Mean	CV (%)
PL	Experiment 1 (2015/2016)	*	–	–	8.780	10.750
	Experiment 2 (2016/2017)	*	–	–	9.130	7.040
	Experiment 3 (2017/2018)	*	–	–	7.800	8.510
	Joint	*	*	*	8.570	8.899
BSL	Experiment 1 (2015/2016)	*	–	–	12.110	7.530
	Experiment 2 (2016/2017)	*	–	–	12.200	6.410
	Experiment 3 (2017/2018)	*	–	–	12.080	5.850
	Joint	*	ns	*	12.131	6.635
CSL	Experiment 1 (2015/2016)	*	–	–	26.600	2.970
	Experiment 2 (2016/2017)	*	–	–	27.050	5.270
	Experiment 3 (2017/2018)	*	–	–	24.860	6.610
	Joint	*	*	*	26.172	5.105
TL	Experiment 1 (2015/2016)	*	–	–	47.500	2.560
	Experiment 2 (2016/2017)	*	–	–	48.380	3.200
	Experiment 3 (2017/2018)	*	–	–	44.740	3.830
	Joint	*	*	*	46.874	3.217
NPB	Experiment 1 (2015/2016)	*	–	–	11.410	10.410
	Experiment 2 (2016/2017)	*	–	–	9.910	11.580
	Experiment 3 (2017/2018)	*	–	–	9.160	8.550
	Joint	*	*	*	10.161	10.388

Continuation Table 2

NSB	Experiment 1 (2015/2016)	*	–	–	2.590	21.730
	Experiment 2 (2016/2017)	*	–	–	2.480	17.980
	Experiment 3 (2017/2018)	*	–	–	2.080	15.480
	Joint	*	*	ns	2.385	19.068
TBN	Experiment 1 (2015/2016)	*	–	–	14.000	11.580
	Experiment 2 (2016/2017)	*	–	–	12.390	11.000
	Experiment 3 (2017/2018)	*	–	–	11.240	8.700
	Joint	*	*	ns	12.545	10.736
PDM	Experiment 1 (2015/2016)	*	–	–	0.260	12.060
	Experiment 2 (2016/2017)	*	–	–	0.230	9.180
	Experiment 3 (2017/2018)	*	–	–	0.210	11.180
	Joint	*	*	*	0.234	10.991
BSDM	Experiment 1 (2015/2016)	*	–	–	2.170	13.060
	Experiment 2 (2016/2017)	*	–	–	1.640	8.960
	Experiment 3 (2017/2018)	*	–	–	1.800	12.720
	Joint	*	*	*	1.869	12.126
CSDM	Experiment 1 (2015/2016)	*	–	–	0.670	7.410
	Experiment 2 (2016/2017)	*	–	–	0.530	8.080
	Experiment 3 (2017/2018)	*	–	–	0.590	11.500
	Joint	*	*	*	0.597	9.112
TDM	Experiment 1 (2015/2016)	*	–	–	3.110	10.270
	Experiment 2 (2016/2017)	*	–	–	2.400	7.700
	Experiment 3 (2017/2018)	*	–	–	2.600	10.970
	Joint	*	*	*	2.701	9.953
GY	Experiment 1 (2015/2016)	*	–	–	9.970	14.970
	Experiment 2 (2016/2017)	*	–	–	9.260	10.570
	Experiment 3 (2017/2018)	*	–	–	8.320	10.470
	Joint	*	*	*	9.184	12.482

(1) Traits: PL: peduncle length (considering the distance between the collar of the flag leaf and the first branch), in cm; BSL: branching space length, in cm; CSL: central spike length, in cm; TL: tassel length, in cm; NPB: number of primary branches; NSB: number of secondary branches; TBN: tassel branch number; PDM: peduncle dry matter (considering the region between the flag leaf collar and the first branch); BSDM: branching space dry matter, in g; CSDM: central spike dry matter, in g; TDM: tassel dry matter, in g; and GY: grain yield in Mg ha^{-1} at 13% moisture.*Significant effect by the F-test at a 5% probability error. ns: not significant

variation is classified as low when less than 10%, medium from 10 to 20%, high from 20 to 30%, and very high when higher than 30%. Thus, the coefficient of variation was classified as low for 18 cases, medium for 17 cases, and high for only one case. Overall, the high experimental precision lends credibility to the genetic divergence study.

The cultivars were separated into groups with different numbers of groups formed for each trait in each experiment based on the Scott-Knott test. The trait with the lowest number of groups was grain yield, with two groups in experiment 1 (Table 3) and three groups in experiments 2 (Table 4) and 3 (Table 5). Simon *et al.* (2012) studied the grain yield of 19 single maize hybrids, evaluated in the 2007/2008 growing season and 2008/2008 off-season, and verified the formation of two and four groups, respectively. Alves *et al.* (2015) evaluated the nutritional quality and grain yield in 18 maize cultivars and observed the formation of two groups for grain yield. Moreover, the number of groups formed for GY was similar to that obtained in this study, which can be explained by the high yield potential of maize hybrids when grown using appropriate cultivation techniques and favorable environments.

Table 3 – Means of 12 traits evaluated in 20 maize cultivars in the 2015/2016 agricultural year

Cultivar	PL	BSL	CSL	TL	NPB	NSB	TBN	PDM	BSDM	CSDM	TDM	GY
20A55	10.248 a	14.828 a	24.548 e	49.625 c	13.467 b	2.717 b	16.183 b	0.356 a	3.330 a	0.878 a	4.564 a	9.906 b
30F53	6.983 c	9.387 d	30.888 b	47.258 c	6.767 d	0.917 d	7.683 d	0.204 d	1.464 d	0.857 a	2.526 d	11.163 a
AG8780	11.337 a	14.915 a	22.935 f	49.187 c	11.817 c	3.750 a	15.567 b	0.363 a	2.248 c	0.476 c	3.087 c	10.728 a
BM3066	7.762 b	13.468 b	21.353 g	42.583 e	18.633 a	3.717 a	22.350 a	0.256 c	3.145 a	0.670 b	4.071 a	11.097 a
DKB290	11.397 a	15.783 a	21.482 g	48.662 c	12.700 b	3.900 a	16.600 b	0.401 a	2.824 b	0.537 c	3.762 b	9.652 b
MS2010	10.492 a	12.420 b	28.707 c	51.618 b	14.933 b	3.767 a	18.700 b	0.266 c	2.664 b	0.689 b	3.619 b	12.728 a
MS2013	8.245 b	13.148 b	26.595 d	47.988 c	14.183 b	4.000 a	18.183 b	0.238 c	3.406 a	0.856 a	4.500 a	10.341 a
MS3022	8.893 b	10.803 c	24.870 e	44.567 e	13.400 b	3.233 b	16.633 b	0.297 b	2.775 b	0.730 b	3.802 b	10.029 a
StatusVIP	8.750 b	15.788 a	19.305 h	43.843 e	19.817 a	4.350 a	24.167 a	0.322 b	2.871 b	0.550 c	3.743 b	9.773 b
SX7331	10.633 a	15.190 a	23.285 f	49.108 c	17.433 a	3.367 a	20.800 a	0.383 a	2.822 b	0.580 c	3.784 b	10.176 a
30A68	10.025 a	13.195 b	31.742 a	54.962 a	9.883 c	2.050 c	11.933 c	0.329 b	2.084 c	0.773 b	3.186 c	11.160 a
AG9025	5.738 c	10.743 c	29.937 b	46.418 d	8.950 c	1.433 c	10.383 c	0.133 e	1.733 d	0.692 b	2.558 d	8.240 b
AM9724	6.785 c	12.605 b	27.338 d	46.728 d	10.450 c	3.833 a	14.2833 b	0.166 e	2.402 c	0.718 b	3.286 c	11.703 a
AS1666	10.200 a	9.092 d	28.813 c	48.105 c	6.733 d	1.650 c	8.383 d	0.260 c	1.362 d	0.694 b	2.316 d	8.963 b
AS1677	5.553 c	11.373 c	28.162 c	45.088 e	8.050 d	1.800 c	9.850 c	0.121 e	1.496 d	0.572 c	2.190 d	8.703 b
Celeron	11.087 a	10.680 c	26.970 d	48.737 c	11.067 c	2.050 c	13.117 c	0.306 b	1.818 d	0.562 c	2.686 d	7.943 b
DKB230	6.295 c	12.698 b	24.783 e	43.777 e	10.100 c	2.500 b	12.600 c	0.124 e	1.190 e	0.334 d	1.648 e	8.645 b
P1630	8.695 b	8.322 d	30.708 b	47.725 c	6.400 d	0.267 d	6.667 d	0.201 d	0.719 e	0.750 b	1.669 e	8.640 b
P2530	8.060 b	7.117 e	32.230 a	47.407 c	4.550 e	0.000 d	4.550 e	0.217 d	0.849 e	0.817 a	1.883 e	7.922 b
SHS7915	8.427 b	10.705 c	27.410 d	46.542 d	8.850 c	2.567 b	11.417 c	0.243 c	2.231 c	0.755 b	3.228 c	11.808 a

PL: peduncle length (considering the distance between the collar of the flag leaf and the first branch), in cm; BSL: branching space length, in cm; CSL: central spike length, in cm; TL: tassel length, in cm; NPB: number of primary branches; NSB: number of secondary branches; TBN: tassel branch number; PDM: peduncle dry matter (considering the region between the flag leaf collar and the first branch); BSDM: branching space dry matter, in g; CSDM: central spike dry matter, in g; TDM: tassel dry matter, in g; and GY: grain yield in Mg ha^{-1} at 13% moisture. Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at a 5% probability

Table 4 – Means of 12 traits evaluated in 20 maize cultivars in the 2016/2017 agricultural year

Cultivar	PL	BSL	CSL	TL	NPB	NSB	TBN	PDM	BSDM	CSDM	TDM	GY
20A55	10.164 b	15.464 a	26.070 c	51.697 b	11.333 d	3.061 b	14.394 c	0.331 b	2.663 a	0.657 a	3.651 a	8.476 b
30F53	7.991 c	8.582 e	31.009 a	47.582 c	5.545 g	0.576 d	6.121 f	0.187 d	0.976 e	0.641 a	1.804 e	9.683 a
AG8780	10.618 b	16.215 a	24.609 d	51.442 b	11.152 d	3.424 a	14.576 c	0.290 c	1.966 b	0.384 d	2.640 c	11.101 a
BM3066	6.276 e	12.427 b	24.500 d	43.203 d	13.939 c	3.697 a	17.636 b	0.175 d	2.176 b	0.543 b	2.894 b	11.756 a
DKB290	10.736 b	14.749 a	24.049 d	49.533 b	9.546 e	3.061 b	12.606 c	0.261 c	1.876 b	0.388 d	2.525 c	10.168 a
MS2010	10.546 b	11.664 b	26.627 c	48.836 c	11.788 d	3.061 b	14.849 c	0.207 d	1.372 d	0.491 c	2.069 d	10.203 a
MS2013	8.691 c	11.794 b	27.239 c	47.724 c	13.242 c	3.606 a	16.849 b	0.173 d	1.977 b	0.618 a	2.767 b	11.045 a
MS3022	8.512 c	10.585 c	25.455 d	44.552 d	11.667 d	2.636 b	14.303 c	0.252 c	2.029 b	0.634 a	2.914 b	8.489 b
StatusVIP	9.467 b	16.409 a	22.155 d	48.030 c	17.697 a	3.758 a	21.455 a	0.330 b	2.573 a	0.487 c	3.390 a	10.551 a
SX7331	12.652 a	15.597 a	25.155 d	53.403 a	15.242 b	3.182 b	18.424 b	0.440 a	2.464 a	0.527 b	3.431 a	11.094 a
30A68	10.736 b	12.324 b	32.879 a	55.939 a	8.212 e	2.485 b	10.697 d	0.314 b	1.688 c	0.628 a	2.630 c	9.875 a
AG9025	7.161 d	12.394 b	28.118 b	47.673 c	8.333 e	2.121 c	10.455 d	0.146 e	1.476 d	0.512 c	2.134 d	8.696 b
AM9724	6.821 e	12.236 b	27.021 c	46.079 c	10.061 e	3.818 a	13.879c	0.115e	1.713c	0.571b	2.399 c	9.850 a
AS1666	10.218 b	9.603 d	27.203 c	47.024 c	6.576 f	1.636 c	8.212 e	0.222 d	1.023 e	0.484 c	1.728 e	7.378 c
AS1677	4.773 f	12.009 b	27.049 c	43.830 d	7.546 f	1.515 c	9.061 d	0.092 e	1.035 e	0.434 c	1.560 e	8.467 b
Celeron	11.349 a	10.991 c	27.936 b	50.276 b	9.394 e	1.909 c	11.303 d	0.267 c	1.407 d	0.472 c	2.145 d	7.176 c
DKB230	7.385 d	11.903 b	24.036 d	43.324 d	7.667 f	2.606 b	10.273 d	0.126 e	0.983 e	0.279 e	1.388 e	7.875 b

Continuation Table 4

P1630	11.812 a	10.894 c	29.618 b	52.324 b	7.121 f	0.606 d	7.727 e	0.276 c	0.851 e	0.559 b	1.686 e	5.838 c
P2530	8.058 c	8.355 e	30.694 a	47.106 c	4.909 g	0.030 d	4.939 f	0.208 d	0.882 e	0.679 a	1.769 e	6.666 c
SHS7915	8.730 c	9.770 d	29.621 b	48.121 c	7.212 f	2.818 b	10.030 d	0.195 d	1.679 c	0.622 a	2.496 c	10.903 a

PL: peduncle length (considering the distance between the collar of the flag leaf and the first branch), in cm; BSL: branching space length, in cm; CSL: central spike length, in cm; TL: tassel length, in cm; NPB: number of primary branches; NSB: number of secondary branches; TBN: tassel branch number; PDM: peduncle dry matter (considering the region between the flag leaf collar and the first branch); BSDM: branching space dry matter, in g; CSDM: central spike dry matter, in g; TDM: tassel dry matter, in g; and GY: grain yield in Mg ha^{-1} at 13% moisture. Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at a 5% probability

Table 5 – Means of 12 traits evaluated in 20 maize cultivars in the 2017/2018 agricultural year

Cultivar	PL	BSL	CSL	TL	NPB	NSB	TBN	PDM	BSDM	CSDM	TDM	GY
20A55	7.512 c	15.308 b	25.108 b	47.928 a	10.900 c	2.667 b	13.567 c	0.252 d	2.879 a	0.757 a	3.887 a	8.712 a
30F53	6.315 c	9.868 e	29.977 a	46.160 a	5.367 f	0.417 e	5.783 g	0.207 e	1.336 c	0.769 a	2.311 c	7.664 b
AG8780	10.930 a	16.368 a	20.755 c	48.053 a	10.983 c	3.433 a	14.417 c	0.319 b	2.090 b	0.401 c	2.809 b	9.150 a
BM3066	6.932 c	12.872 c	24.573 b	44.377 b	13.983 b	2.800 b	16.783 b	0.219 e	2.689 a	0.686 b	3.594 a	9.374 a
DKB290	9.307 b	16.727 a	22.633 c	48.667 a	10.350 c	3.183 a	13.533 c	0.303 c	2.612 a	0.484 c	3.399 a	9.737 a
MS2010	8.970 b	11.340 d	24.228 b	44.538 b	11.800 c	2.817 b	14.617 c	0.168 e	1.703 c	0.543 c	2.414 c	8.559 a
MS2013	4.730 e	11.217 d	27.470 a	43.417 b	10.767 c	2.917 b	13.683 c	0.124 f	2.453 a	0.778 a	3.354 a	8.050 b
MS3022	5.950 d	10.712 d	24.845 b	41.507 c	11.850 c	2.467 b	14.317 c	0.189 e	2.468 a	0.6563 b	3.313 a	7.672 b
StatusVIP	8.710 b	16.875 a	17.295 d	42.880 b	15.517 a	3.217 a	18.733 a	0.287 c	2.256 b	0.444 c	2.987 b	9.778 a
SX7331	11.623 a	15.677 b	20.842 c	48.142 a	13.817 b	2.550 b	16.367 b	0.379 a	2.134 b	0.469 c	2.982 b	8.616 a
30A68	8.420 b	12.788 c	29.545 a	50.753 a	7.633 e	1.867 c	9.500 e	0.249 d	1.723 c	0.668 b	2.641 b	9.905 a
AG9025	5.800 d	11.158 d	27.755 a	44.713 b	6.333 f	1.183 d	7.517 f	0.126 f	1.436 c	0.659 b	2.221 c	8.057 b
AM9724	4.403 e	11.833 d	24.627 b	40.863 c	9.033 d	2.933 b	11.967 d	0.100 f	2.068 b	0.620 b	2.789 b	7.357 b
AS1666	8.672 b	8.777 e	23.608 b	41.057 c	5.883 f	1.467 d	7.350 f	0.197 e	1.091 d	0.529 c	1.816 d	7.946 b
AS1677	4.347 e	10.758 d	25.503 b	40.608 c	6.117 f	1.183 d	7.300 f	0.094 f	1.042 d	0.478 c	1.614 d	8.358 b
Celeron	10.830 a	11.357 d	25.807 b	47.993 a	9.617 d	1.883 c	11.500 d	0.295 c	1.639 c	0.521 c	2.454 c	8.127 b
DKB230	6.790 c	11.180 d	19.662 c	37.632 d	7.533 e	1.833 c	9.367 e	0.109 f	0.860 d	0.269 d	1.238 d	7.340 b
P1630	10.322 a	9.618 e	27.423 a	47.363 a	5.600 f	0.317 e	5.917 g	0.247 d	0.779 d	0.601 b	1.627 d	7.079 b
P2530	7.757 c	7.662 f	27.062 a	42.480 b	3.533 g	0.017 e	3.550 h	0.205 e	0.838 d	0.679 b	1.722 d	4.978 c
SHS7915	7.608 c	9.523 e	28.520 a	45.652 a	6.650 f	2.450 b	9.100 e	0.201 e	1.826 b	0.713 a	2.748 b	10.004 a

PL: peduncle length (considering the distance between the collar of the flag leaf and the first branch), in cm; BSL: branching space length, in cm; CSL: central spike length, in cm; TL: tassel length, in cm; NPB: number of primary branches; NSB: number of secondary branches; TBN: tassel branch number; PDM: peduncle dry matter (considering the region between the flag leaf collar and the first branch); BSDM: branching space dry matter, in g; CSDM: central spike dry matter, in g; TDM: tassel dry matter, in g; and GY: grain yield in Mg ha^{-1} at 13% moisture. Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at a 5% probability

Table 6 – Percentage of the total variation explained by the principal components (PC) and the set of eigenvalues (λ) associated for 20 maize cultivars evaluated in three agricultural years

PC	λ	Accumulated explained %	PL	BSL	CSL	TL	NPB	NSB	TBN	PDM	BSDM	CSDM	TDM	GY
y1	6.620	55.169	0.153	0.344	-0.286	0.089	0.361	0.350	0.370	0.242	0.355	-0.073	0.335	0.277
y2	2.337	74.641	0.484	-0.004	0.284	0.599	-0.115	-0.183	-0.136	0.440	-0.009	0.246	0.082	-0.009
y3	1.750	89.223	-0.354	-0.174	0.346	-0.013	0.011	0.056	0.022	-0.203	0.269	0.655	0.332	0.263
y4	0.623	94.418	-0.082	0.161	0.226	0.316	-0.209	0.238	-0.105	-0.249	-0.155	-0.308	-0.219	0.690
y5	0.301	96.925	-0.419	0.678	-0.023	0.273	-0.237	-0.099	-0.210	-0.069	0.173	-0.034	0.144	-0.351
y6	0.169	98.337	-0.025	0.025	0.352	0.368	0.520	0.022	0.413	-0.376	-0.139	-0.051	-0.175	-0.324
y7	0.150	99.591	0.322	-0.201	0.036	0.075	-0.341	0.638	-0.109	-0.327	0.229	-0.078	0.159	-0.351
y8	0.034	99.877	-0.291	-0.323	0.430	-0.012	0.026	-0.080	0.000	0.323	0.328	-0.592	0.231	-0.060

Continuation Table 6

y9	0.015	100.000	0.343	-0.034	-0.141	0.045	0.052	-0.570	-0.100	-0.530	0.358	-0.188	0.235	0.151
y10	0.000	100.000	0.003	0.004	0.005	-0.005	-0.606	-0.191	0.772	0.000	-0.002	0.000	0.003	0.000
y11	0.000	100.000	-0.008	-0.011	-0.013	0.013	0.002	0.001	-0.003	-0.080	-0.664	-0.125	0.733	0.000
y12	0.000	100.000	0.359	0.468	0.580	-0.562	0.005	0.002	-0.007	-0.002	-0.015	-0.003	0.017	0.000

PL: peduncle length (considering the distance between the collar of the flag leaf and the first branch), in cm; BSL: branching space length, in cm; CSL: central spike length, in cm; TL: tassel length, in cm; NPB: number of primary branches; NSB: number of secondary branches; TBN: tassel branch number; PDM: peduncle dry matter (considering the region between the flag leaf collar and the first branch); BSDM: branching space dry matter, in g; CSDM: central spike dry matter, in g; TDM: tassel dry matter, in g; and GY: grain yield in Mg ha^{-1} at 13% moisture

The principal component analysis considering the joint analysis of the three agricultural years showed that the first and second principal components represented 55.169 and 19.472% of the total variation, while the first four components accumulated 94.418% of the total variance (Table 6). PL, BSL, CSL, NPB, NSB, PDM, BSDM, and TDM were discarded because they were the traits that most contributed to genetic divergence in the last principal components. Thus, the traits that remained for the clustering analysis of cultivars were TL, TBN, CSDM, and GY. GY remained in the analysis for being the fourth principal component that contributed the most to genetic divergence among the cultivars, also showing the highest agronomic interest. Öner (2018) carried out an experiment with spike and tassel traits and observed that tassel length is one of the preferable traits for the study of genetic divergence in maize.

The dissimilarity measures estimated from the generalized Mahalanobis distance (D^2) presented magnitudes that ranged from 1.75 to 172.36, and the relationship between the highest and lowest observed D^2 value was 98.49, indicating the presence of genetic variability among cultivars. The lowest D^2 values were verified among the cultivars AG8780 and DKB290 (1.75), followed by AS1666 and AS1677 (3.12), and DKB290 and Celeron (5.24). The highest distances were found between the cultivars StatusVIP and P2530 (172.36), SX7331 and P2530 (144.13), and StatusVIP and P1630 (124.18) (Table 7). The amplitudes of the estimates scores (D^2) suggest the existence of dissimilarity between these cultivars, which can be recommended for crosses aiming at maximizing hybrid combinations with higher heterotic effect, increasing the possibility of recovering superior genotypes (CRUZ; CARNEIRO; REGAZZI, 2014).

Studies on genetic diversity using generalized Mahalanobis distance as a dissimilarity measure for cluster analysis were carried out in maize cultivars by Alves *et al.* (2015), resulting in four groups, Chandel and Guleria (2019), with the formation of nine groups, Nardino *et al.* (2017), with the formation of eight groups, and Silva *et al.* (2016), who observed the formation of 11 groups.

The dendrogram obtained by the unweighted pair group method with arithmetic mean (UPGMA), using 50% as dissimilarity criterion, showed the formation of six groups of cultivars (Figure 2). Group I was formed by five cultivars (AG8780, DKB290, Celeron, MS2010, and SX7331), group II by one cultivar (30A68), group III by five cultivars (MS3022, AM9724, 20A55, MS2013, and BM3066), group IV by one cultivar (StatusVIP), group V by seven cultivars (30F53, P2530, AG9025, AS1666, AS1677, P1630, and SHS7915), and group VI by one cultivar (DKB230). The UPGMA clustering method was considered the most efficient method for grouping maize cultivars, according to Cargnelutti Filho and Guadagnin (2011). Silva *et al.* (2016) observed that the UPGMA hierarchical method was efficient in identifying groups of superior and contrasting cultivars for traits of highest interest for sweetcorn production.

A significant cophenetic correlation coefficient (CCC) of 0.6017 was obtained from the UPGMA clustering method (p-value $\leq$ 0.05), showing a reliable representation of the genetic distances of the cultivars in the dendrogram. Alves *et al.* (2015) studied the nutritional quality and yield of maize grains and observed a significant CCC value equal to 0.5788 using the UPGMA clustering method. Nardino *et al.* (2017) studied the genetic divergence between different environments and determined a CCC value of 0.60 by the UPGMA method. Silva *et al.* (2016) studied the dissimilarity in progenies of sweetcorn and observed a significant CCC value of 0.65 by the UPGMA method. These results are similar to those observed in the present study, indicating that the matrix data had a satisfactory fit in the graphical representation shown by the dendrogram.

The comparison of the means of groups using the Scott-Knott test showed that the four traits used to group the cultivars had a significant difference. The longest and smallest tassel lengths were observed for groups II and IV, respectively, the total branches number had the highest mean in group IV and lowest mean in group V, the central spike dry matter showed the highest means in groups II, III, and V and the lowest mean in group VI, and groups I, II, III, and IV stood out for having the highest grain yield (Table 8).

Table 7 – Dissimilarity between maize cultivars for tassel length, total branches number, central spike dry matter, and grain yield relative to three agricultural years and based on the generalized Mahalanobis distance (D^2)

C[1]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	50.6	49.5	27.0	34.9	14.0	7.1	17.0	45.4	30.2	28.7	28.4	16.5	47.7	60.5	30.0	96.4	45.3	70.7	27.5
2		93.7	91.7	73.0	66.1	58.2	51.5	146.8	118.7	43.2	13.4	31.1	15.0	25.9	55.2	81.1	17.5	8.1	8.1
3			67.6	1.7	14.5	66.9	66.3	46.5	14.9	31.8	43.6	46.7	49.6	50.3	10.9	40.1	51.6	112.9	58.1
4				53.6	23.1	9.1	9.0	16.7	40.7	88.6	55.3	17.9	74.9	71.4	61.8	89.7	99.4	117.7	50.7
5					8.1	49.6	48.2	41.5	13.9	24.6	29.0	31.3	35.6	37.5	5.2	35.3	38.3	89.9	41.9
6						19.6	23.4	22.7	9.0	28.1	28.0	15.8	41.6	44.8	14.5	55.4	47.9	89.5	31.6
7							5.4	35.6	41.8	56.8	36.0	11.0	56.3	62.5	48.5	98.2	67.2	81.0	30.2
8								36.9	50.7	68.2	26.4	4.9	40.9	41.7	43.9	69.7	59.2	65.1	27.3
9									17.7	98.9	83.3	45.4	103.6	97.6	57.0	88.4	124.2	172.4	91.5
10										45.0	62.4	46.2	80.0	84.0	25.2	79.8	81.0	144.1	72.8
11											28.5	45.0	37.9	55.1	20.1	87.0	21.9	64.1	29.8
12												10.9	2.5	7.9	17.0	36.7	8.1	18.3	7.3
13													20.6	21.6	27.9	48.6	36.1	45.8	10.9
14														3.1	21.9	28.1	7.4	15.3	13.1
15															27.6	15.9	19.3	26.1	19.7
16																33.0	19.5	61.5	35.3
17																	50.9	77.3	61.8
18																		16.4	21.1
19																			25.7

[1] C = cultivars: 1: 20A55, 2: 30F53, 3: AG8780, 4: BM3066, 5: DKB290, 6: MS2010, 7: MS2013, 8: MS3022, 9: StatusVIP, 10: SX7331, 11: 30A68, 12: AG9025, 13: AM9724, 14: AS1666, 15: AS1677, 16: Celeron, 17: DKB230, 18: P1630, 19: P2530, and 20: SHS7915

Figure 2 – Dendrogram obtained by the cultivar clustering method utilizing the hierarchical method of unweighted pair group method with arithmetic mean (UPGMA) from the generalized Mahalanobis distance (D^2) among 20 maize cultivars grouped based on the tassel length, total branches number, central spike dry matter and grain yield. Cophenetic correlation coefficient = 0.6017 and significant at a 5% probability error

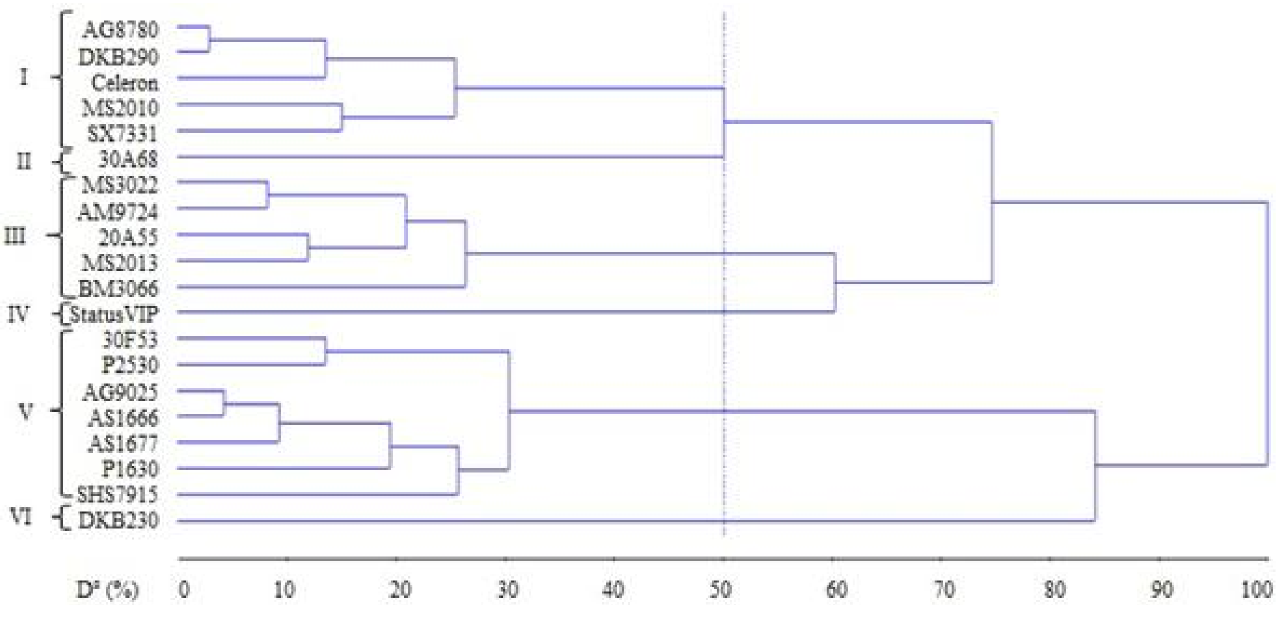


Table 8 – Means of the traits tassel length (TL, cm), total branches number (TBN), central spike dry matter (CSDM, g), and grain yield (GY, Mg ha^{-1}) for 20 maize cultivars allocated into six groups using the UPGMA method and represented in the dendrogram (Figure 2)

Group	Number of cultivars	Cultivar	TL	TBN	CSDM	GY
I	5	AG8780, DKB290, Celeron, MS2010, SX7331	49.213 b	15.132 b	0.502 b	9.677 a
II	1	30A68	53.885 a	10.710 c	0.690 a	10.313 a
III	5	MS3022, AM9724, 20A55, MS2013, BM3066	45.523 c	15.667 b	0.691 a	9.590 a
IV	1	StatusVIP	44.918 c	21.452 a	0.494 b	10.034 a
V	7	30F53, P2530, AG9025, AS1666, AS1677, P1630, SHS7915	46.202 c	7.714 d	0.643 a	8.436 b
VI	1	DKB230	41.578 d	10.747 c	0.294 c	7.953 b

Means of groups not followed by the same letter in the column differ from each other by the Scott-Knott test at a 5% probability

This study proved that tassel traits should be considered in studies of genetic divergence in maize. Tassel length, total branches number, central spike dry matter, and grain yield were the traits that most contributed to genetic divergence and should be considered in maize breeding programs.

CONCLUSIONS

1–There is a genetic divergence between maize cultivars;

2–Tassel length, total branches number, central spike dry matter, and grain yield are the traits that most contribute to the genetic divergence among maize cultivars.

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