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Agronomic Performance and Genetic Divergence in Corn (*Zea mays*) in the Cerrado-Amazon Ecotone

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Authors' contributions

This work was performed in collaboration among all authors. Author RMS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript, under the guidance of authors WFS and LFSS. Author WFS administered the study analyzes. Authors MRA and ZDS managed the bibliographic research, supported by authors JMP, LRSB, CNML, VCD, TASLB and ALLM. Authors MO and ZDS reviewed the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this work is to study the agronomic performance and genetic divergence in corn in the Cerrado-Amazon ecotone. The trials were conducted in the 2017/18 harvest at a property in the state of Pará. The experimental design was a randomized block with nine treatments and three

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replications, where the treatments are represented by nine cultivars of corn. The characteristics to evaluate agronomic performance and genetic divergence were: ear height (cm), plant height (cm), ear length (cm), ear diameter (mm), number of rows, number of grains per row and grain yield (kg ha^{-1}). The cultivars were separated into a multivariate model in five groups using the Tocher optimization method. The cultivar AG 1051 showed the best agronomic performance. The results of genetic divergence were according to the generalized distance of Mahalanobis (D^2), with the commences AG 8088 x CATIVERDE and AG 1051 x AL BANDEIRANTE, the most promising for future crosses.

Keywords: Mahalanobis; nitrogen; productivity; randomized block; variability.

1. INTRODUCTION

The corn (*Zea mays* L.) is extremely important for the world economy and is produced throughout the Brazilian territory [1]. It can be consumed in nature or used in the food industry as a raw material of a range of products, but most of the production is intended for animal feed, highlighted by being an important energy source in the diets [2,3].

According to the national supply company (CONAB) [4], in the 2018/19 crop, the state of Pará reached the productivity of 3.055 kg ha^{-1}, than the total national average of 5.605 kg ha^{-1}. This low productivity can be the result of high temperatures, low technological level employed and the lack of selection of cultivars adapted to the region [5].

The Cerrado-Amazon Ecotone is a transition zone between the Cerrado and Amazon Bioms and occupies an area of approximately 41.4 million hectares, a part of Pará, specifically the southern region, is located within this area [6]. This transitional zone contains some of the characteristics of these two ecosystems [7]. For high corn yield in this ecotone, it is necessary to use cultivars for these environmental conditions [8].

The productivity of a crop is related to 60% to genetic factors and 40% to environmental factors, and the climatic elements, water availability and soil fertility can be highlighted [9]. Among the essential nutrients for plants, nitrogen (N), stands out because it is the most demanded by the crop, being responsible for vegetative growth and directly influencing the grain yield, participates in photosynthesis, increases the Total percentage of proteins, increase the weight of the spike and increase the percentage of oil [10].

Following the reasoning of the selection of promising materials for the region of interest, studies of genetic divergence are essential for the knowledge of the genetic divergence existing in the germplasm banks, enabling the monitoring, Assisting in the identification of possible duplicates and providing parameters for the choice of parents, which, when crossed, allow greater heterotic effect, increasing the chances of obtaining higher genotypes in segregating generations [11].

The agronomic performance in corn cultivation has been studied by several authors [12–16].

And genetic divergence also [1,5,17–19], however, there are few studies developed in the northern region of the country, more specifically in the Cerrado-Amazon transitional zone. In view of the above, the present work aims to study the agronomic performance and genetic divergence in maize in the Cerrado- Amazon Ecotone.

In a breeding program, the first step consists in choosing the parents, since from of them will be generated the materials desired by the breeder [20]. That is, the materials with the greatest potential for the traits of interest will be selected and crossed to obtain a new genotype. In the case of corn, the greater the genetic divergence, the greater the tendency of occurrence of a superior individual.

2. MATERIALS AND METHODS

In the year 2018, two trials were conducted at the Victoria property, located (8º18'32" S 50º36'58") In the municipality of Santa Maria das Barreiras, State of Pará region of the ecotone between the Amazon and the Cerrado. The climate of the region is of type Aw according to the Köppen classification, which indicates a tropical climate with the dry season in winter [21].

Two maize cultivars competition assays were installed, one of which was installed under low nitrogen, with 0 kg ha^{-1} of N in coverage, and one under high nitrogen, with 120 kg ha^{-1} of N in

coverage. These doses were determined by the lowest and highest expected yield for the maize crop [22]. The experimental design used in each assay was randomized blocks with nine treatments and three replications. The treatments were six corn hybrids: PR27D28, 2B655PW, AG1051, AG8088, BR206 and BRS3046; and three Open Pollination Population: AL BANDEIRANTE, ANHEMBI, and CATIVERDE.

The experimental portion used was composed of four rows of 5.0 m, spaced 0.9 m Between lines. The useful area of the plot was only the two central rows, discarding 0.5 m of the ends of these ranks. Totaling an area of 972 m^2.

Soil tillage was carried out with a Harrow grid followed by the use of a leveler grid. The basic fertilization was performed manually using 300 kg ha^{-1} of N-P_2O_5-K_2O formulation 5-25-15+0.5% Zn.

Sowing was performed in January 2018, a manual groove with an average depth of 0.04 m. After emergence, the thinning was performed leaving a spacing of 0.2 m between plants, obtaining a population of 55.555 plants ha^{-1}.

The cover fertilization was performed with a 120 kg ha^{-1} N in the high N assay. The source used was the urea (45% de N), totaling 266 kg ha^{-1} of urea, being divided into two applications into the stages: V4 e V8 (4 e 8 completely open sheets, respectively).

For the study of genetic divergence, the following variables were used in the multivariate model: plant height (cm), spike height (cm), spike length (mm), spike diameter (mm), number of rows per spike, number of grains per row, and grain yield (kg ha^{-1}).

The measures of dissimilarities were determined according to the multivariate analysis model, which allowed obtaining the matrices of dissimilarities, residual covariances and the averages of the populations. The Tocher grouping method was applied [23], using the generalized Mahalanobis distance (D^2) [24], and Singh criterion [25] to quantify the relative contribution of the seven characteristics.

Statistical analyses were the analysis of variance (Test F; $p<0.05$) and for the analysis of the agronomic performance, the Scott-Knott [26] means multiple comparison test was used ($p<0.05$), performed using the Genes program [27].

3. RESULTS AND DISCUSSION

In the analysis of variance (Table 1) the coefficients of variation of the characteristics were: 3.60% for spike height (SH), 2.56% for plant height (PH), 4.12% for spike length (SL), 2.12% for spike diameter (SD), 3.28% for number of rows per spike (NR), 3.97% number of grains per row (NGR) and 6.17% for productivity (PROD). These data cause the experiment to be classified as high-precision experimental, due to the categorization of the coefficient of variation as low [28].

The mean SH was 102 cm, varying from 127 cm (AG 1051) the 79 cm (AG 8088) and five different groups of averages were separated. The group with the highest means comprised of the cultivar's AG 1051 (127 cm), CATIVERDE (123 cm) e PR27D28 (121 cm), AG 8088 is inserted in the group with the lowest means, with 79 cm for this feature. A high height of the insertion of the spike is undesirable, as in addition to influencing the breaking of the stem and tipping [29], also disfavors the accumulation of carbohydrates in maize grains, because about 50% Of these carbohydrates are from the leaves of the upper third of the plant [30].

The lowest means, with 79 cm for this feature. A high height of the insertion of the spike is undesirable, as in addition to influencing the breaking of the stem and tipping [29], also disfavors the accumulation of carbohydrates in maize grains, because about 50% Of these carbohydrates are from the leaves of the upper third of the plant [30].

The PH characteristic showed an average of 204 cm, the values ranged from 218 cm (CATIVERDE) the 193 cm (BRS 3046 e AG 8088), dismembering the cultivars into four medium groups. Just like Alvarez, et al. [8], in this work the plants of higher height coincided with the higher height of the insertion of the spike (AG 1051 and CATIVERDE), demonstrating the correlation between these two characteristics.

The SL ranged from 19.45 cm (AG 1051) a 16.68 cm (AL BANDEIRANTE) Distinguishing the nine cultivars in only two groups of mean, being only the cultivars AL BANDEIRANTE and CATIVERDE classified in the group with the lowest averages. And the average of this character was 18.58 cm. This result is higher than that found by Quiessi, et al. [31], Bertolini

et al. [32]; Sousa; Yuyama [29], that found values of 18.0, 16.9 and 15.0 respectively.

The values obtained from SD were grouped into four statistical groups, the group with the highest averages consisting of the cultivar's AG 1051 (52.23 mm), AG 8088 (53.72 mm) and BRS 3046 (53.03 mm) and in the group with the lowest mean cultivars AL BANDEIRANTE (45.13 mm) and CATIVERDE (45.30 mm). And the overall average for this characteristic was 49.80 mm.

The cultivars AG 8088, BRS 3046, 2B655PW and AG 1051 obtained the highest number of rows per spike, with 16.3, 15.7, 15.7 and 15.3 rows respectively. While the cultivar CATIVERDE, with 14 ranks was with the lowest NRS. And the average for this characteristic was 15.2 rows per spike. This result shows higher values than those found by Sousa & Yuyama [29] and Bertolini, et al. [32], which were 14.6 e 14.67 rows, respectively.

As for the NGR, the values ranged from 38 (AG 1051) a 29 (CATIVERDE), While the average was 33 grains per row. Balbino Júnior, et al. [33] states that among the variables that determine corn yield is the NR and NGR that characterize the number of grains formed in a spike.

Regarding grain yield, the genotypes AG1051, BRS 3046, AG 8088 e BR 206 with mean 8.325, 8.261, 8.139 e 8.029 kg ha^{-1}, respectively, from the group with the highest mean. The results obtained were higher than the average productivity in the state of Pará [4], that was from 3.055 kg ha^{-1}, and also the found by Santos, et al. [34] and Souza, et al. [35], de 5.889 e 6.391 kg ha^{-1}, respectively.

The combination of cultivars AG 8088 x CATIVERDE (Table 2) was considered the most divergent (D^2= 270,61), Followed by AG 1051 x AL BANDEIRANTE (D^2 = 230,45). The smallest distances were among the combination's AG 8088 x BRS 3046 (D^2 = 11,78) and 2B655PW x BRS 3046 (D^2 = 19,88).

It is observed that greater distances represent materials that probably came from different germplasm banks, and shorter distances, the materials that are probably from the same germplasm bank. Thus, the analysis of the genetic distance between the materials leads to a faster, less use of manpower and financial resources that will be used in future programs to improve corn crops, since it allows evaluating different materials and promising to insert into the breeding program [14,36].

According to Ramalho, et al. [37], to achieve, the so desired, maximum level of heterosis is necessary to make combinations between materials that are complementary, that is, on the loco where there are recessive alleles in one material, in the other the allele must be dominant and vice versa, thus generating a greater degree of heterosis.

The grouping analysis by the Tocher method separates the materials into distinct groups so that there are intragroup homogeneity and intergroup heterogeneity [11]. After the dissimilarity measures were obtained (D^2) the cultivars are grouped into five groups (Table 3).

The first large group separated by the Tocher method consists of three cultivars (2B655PW, AG8088 and BRS 3046), the second by

Table 1. Summary of the analysis of variance of the characteristic of spike height in cm (SH), plant height in cm (PH), spike length in cm (SL) and spike diameter in mm (SD), number of rows (NR), number of grains per row (NGR) and grain yield in kg ha^{-1} (PROD), of 9 corn cultivars

Cultivars	SH		PH		SL		SD		NR		NGR		PROD	
PR27D28	121	a	209	b	18.68	a	50.32	b	14.8	b	31	c	7.468	b
2B655PW	85	d	203	c	19.18	a	50.48	b	15.7	a	32	c	7.467	b
AG 1051	127	a	217	a	19.45	a	52.23	a	15.3	a	38	a	8.325	a
AG 8088	79	e	193	d	19.43	a	53.72	a	16.3	a	34	b	8.139	a
AL BANDEIRANTE	94	c	197	c	16.68	b	45.13	d	15.2	b	30	c	5.317	c
ANHEMBI	93	c	207	b	19.03	a	47.30	c	14.8	b	30	c	5.761	c
BR 206	106	b	200	c	18.92	a	50.72	b	14.8	b	35	b	8.029	a
BRS 3046	90	c	193	d	18.73	a	53.03	a	15.7	a	35	b	8.261	a
CATIVERDE	123	a	218	a	17.13	b	45.30	d	14.0	c	29	b	5.919	c
Mean	102		204		18.58		49.80		15.2		33		7.187	
CV %	3.60		2.56		4.12		2.12		3.28		3.97		6.17	

Mean followed by the same lowercase letter in the column belong to the same group, by the grouping criterion of Scott & Knott (1974), the 5% of significance

Table 2. Mahalanobis distances estimation (D^2) maximum and minimum of corn cultivars

Genotype	Greater distance		Shortest distance	
PR27D28	156.84	(AG 8088)	33.09	(BR 206)
2B655PW	159.67	(CATIVERDE)	19.88	(BRS 3046)
AG 1051	230.45	(AL ANDEIRANTE)	38.91	(PR27D28)
AG 8088	270.61	(CATIVERDE)	11.78	(BRS 3046)
AL BANDEIRANTE	230.45	(AG 1051)	25.54	(ANHEMI)
ANHEMBI	182.94	(AG 1051)	25.54	(AL BANDEIRANTE)
BR 206	97.14	(CATIVERDE)	25.94	(BRS 3046)
BRS 3046	198.09	(CATIVERDE)	11.78	(AG 8088)
CATIVERDE	270.61	(AG 8088)	42.12	(PR27D28)
Longest distance	270.61		(AG 8088 and CATIVERDE)	
Shortest distance	11.78		(AG 8088 and BRS 3046)	

Table 3. Grouping of nine corn cultivars by the Tocher method [23], based on Mahalanobis generalized distance

Group	Access
I	2B655PW, AG 8088 and BRS 3046
II	AL ANDEIRANTE and ANHEMBI
III	PR27D28 and BR 206
IV	AG 1051
V	CATIVERDE

two (AL BANDEIRANTE and ANHEMBI), The third group is also formed by two cultivars (PR27D28 and BR 206), while the fourth (AG 1051) and the fifth (CATIVERDE) group are formed by only one genotype each. Groups that are formed only by one material indicate that this is divergent in relation to the others, facilitating the prospecting of work in breeding programs [38].

Through the Tocher optimization method, the average intergroup distances are obtained (Table 3), detailing which groups that most diverge from entering themselves.

Table 4. Mean distances between the groups formed by the analysis of genetic divergence in nine corn cultivars

Groups	II	III	IV	V
I	89.45	80.85	158.38	209.46
II		88.39	206.70	87.32
III			48.42	69.63
IV				118.69

The smallest distances obtained between the groups were III and IV (48.42) and III and V (69.63). On the other hand, the longest distances obtained were between the groups I and V (209.46) and II and IV (206.70), indicating the most divergent groups. These high values represented in Table 4 highlight the divergence between the cultivars of distinct groups [34].

Emphasize the divergence among the divergent groups can be used as a basis for developing lineages that will serve as future hybrid crossings since they require complementary locos [39].

Of the seven characteristics evaluated in Table 5, the most contributed to the divergence was the SH (47.69%), followed by the SD (18.66%) and the smallest contributions were from the NGR (2.26%) e SL (1.85%). Therefore, the NGR and SL characteristics can be discarded from future assessments, because they contribute little to discriminate the evaluated materials, and can then reduce time, labor and costs in breeding programs [38,40].

Table 5. The relative contribution of the traits of nine corn cultivars to diversity through Mahalanobis generalized distance, following Singh's criterion [25]

Variable	Contribution (%)
SH	47.69
PH	7.83
SL	1.85
SD	18.66
NR	2.26
NGR	8.40
PROD	13.31

4. CONCLUSION

The cultivar AG 1051 presented the best agronomic performance. Proving a direct correlation between initial characteristics and final grain yield, keeping it in the "a" grouping for all characteristics in the Schott-Knott method [26].

The cultivars AG 8088 x CATIVERDE and AG 1051 x AL BANDEIRANTE, are the most promising combinations for breeding in the Cerrado-Amazon Ecotone. Because they condition greater distances in the characteristics evaluated for genotypic progression. These characteristics, plant height, ear diameter and grain yield were the main contributors to genetic divergence.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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