Multivariate analysis of sorghum hybrids cultivated in the semiarid region

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SUMMARY

The objective of this study was to evaluate the agronomic characteristics of the plant and silage based on the principal component analysis of the clusters, dispersion plot and genetic correlation between Sorghum (L.) bicolor hybrids. Twenty sorghum hybrids were used in a randomized blocks design with three replications. The number of tillers, total plant height, leaf/stem and live matter/dead mass ratios, and the dry matters of leaf, stem, panicle and grains were evaluated. The means were compared using the Student Newman Keuls (SNK) test at a significance level of P<0.05. Three principal component analysis were responsible an accumulation of about 67% of all phenotypic diversity (number of tillers, lodging and total green forage mass). There was a positive and strong correlation between the productivity variables (green forage mass with height, leaf/stem ratio, leaf dry mass). There was genetic variability within the groups, indicating that some hybrids can be highlighted by agronomic characteristics (number of tillers number, lodging, total green forage mass, total dry forage mass, height, leaf/stem ratio, dead material, leaf dry mass), and thus group II (12F042224, FEPAGRO 11.9929012, 9929026, SF 25, 947216, 12F042150, 9929012, PROG 134 IPA) presented the hybrids more productive and more suitable for the production of silage in semiarid regions, among the four groups.

INTRODUCTION

Sorghum (Sorghum bicolor (L.) moench) belongs to the Poaceae family and is a cereal with high genetic variability. It can be used for the production of hay, silage, grains, for cutting, and grazing. An alternative in regions of semi-arid climate is the silage of sorghum, due to its phenological characteristics, ease of sowing, handling, harvesting and storage, besides its great nutritional value and chemical characteristics of the plant. The indication of hybrids adapted to regions of semi-arid climate is extremely important for the correct use of sorghum (Silva et al., 2017, p.16), aiming the increase of feed security for the herds.

For the cultivation of sorghum, agronomic characteristics such as the production of green and dry forage mass, plant height, chemical composition and silage quality, are important in the characterization of promising hybrids for animal feeding. In this case, it is necessary to know the genetic parameters related to these characteristics and their correlations, since the knowledge of the genetic association between them is highly relevant (Malebele et al., 2015, p. 207), to select the hybrids that are more suitable for semiarid regions.

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Sorghum has chemical characteristics, similar to corn, that improves the nutritional value and high levels of soluble carbohydrates that improve the fermentation of silage, its use makes possible the replacement of corn in animal feeds with the reduction of costs and no loss of performance (SRICHUWONG et al., 2017, p.8)

Multivariate analysis techniques have been used for characteristics expressed by quantitative and qualitative variables and for evaluation of sorghum hybrids in the semi-arid region. The determination of genetic divergence with the use of multivariate analysis may allow the identification of genetic variability sources. The best application is the study of sets of variables associated with the superiority of the hybrids, grouping and importance of the variables for the study of genetic diversity. It is possible to identify superior individuals through the mean test through the significant difference, who was better for certain characteristics (Jimmy et al., 2017, p.48). This quantification can be performed using different technics, including agronomic, morphological, and molecular characteristics. For quantitative variables, the variability can be accessed using measures of dissimilarity, such as: Euclidean distance, principal component analysis, canonical variables and agglomerative methods (Cruz and Regazzi, 2001, p.390) can also be used as tools to identify superior genotypes. The Ward grouping method (Ward, 1963) called minimum variance (Mingoti, 2005, p.297) forms clusters by maximizing homogeneity, aiming to minimize the sum of squares of the residuals within the cluster.

Thus, this study aimed to evaluate the agronomic characteristics of the plant and silage based on the principal component analysis, dispersion plot, and genetic correlation between forage sorghum hybrids.

MATERIAL AND METHODS

EXPERIMENTAL SITE
The experiment was carried out in Alvorada do Gurgueia, Piauí. The city of Alvorada do Gurgueia is located at latitude 08°25’28” south and longitude 43°46’38” west, and altitude of 281 meters. The climate at the location is classified as BSh, hot semiarid, according to the Köppen classification of 1936, described by Medeiros et al. (2013, p.660) and Alvares et al. (2013, p.719). Data on rainfall, air relative humidity and maximum and minimum temperature during the experimental period from November 2014 to April 2015 can be observed in Figure 1.

EXPERIMENTAL DESIGN, AREA AND HYBRIDS TESTED
The experimental design was randomized complete blocks with three replicates. The total experimental area had 458.8 m², divided into 75 plots of 2.8 m² each (2.8 m x 1 m) with a space between rows of 0.70 m, and the plots were separated by non-cultivated spaces of 0.5 m between them and 2.00 m between blocks.

The hybrids tested were: 9929036, 9929026, 947216, 947030, 947254, 947072, 947252, SF15, SF11, SF25, PROG134IPA, 12F042226, 12F042422, 12F042496, BRS506, provided by Embrapa Corn and Sorghum, classified as dual-purpose sorghums.

PLANTING AND FERTILIZATION

Before the experiment begun, a soil sample from the 0-20 cm layer of the experimental area was collected for analysis and chemical characterization (carried out at the Soil Analysis Center, CPCE). The soil was classified as dystrophic yellow latosol, following Raij (1991), and had the following characteristics: pH = 5.40; phosphorus (P) = 9.6 mg dm⁻³; potassium (K) = 21.19 mg dm⁻³; calcium (Ca) = 2.4 cmol dm⁻³; magnesium (Mg) = 0.6 cmol dm⁻³; aluminum (Al) = 0.00 cmol dm⁻³; hydrogen + aluminum (H + Al) = 3.5 cmol dm⁻³; sum of bases (SB) = 3.1 cmol dm⁻³; Effective CEC (t) = 3.1 cmol dm⁻³; CEC at pH 7.0 (T) = 6.5 cmol dm⁻³; saturation (V) = 46.8%; saturation by aluminum (m) = 0.0%, and organic matter (OM) = 0.0%.

Based on the soil base saturation and crop requirements, it was not necessary to perform soil correction based on the soil base saturation. For the base fertilization 50 kg N ha⁻¹ (urea), 50 kg K ha⁻¹ (potassium chloride), and 30 kg Pha⁻¹ (single superphosphate) was applied, following the recommendations of (Sousa and Lobato, 2004, p.177). Planting was done at the beginning of the rainy season by sowing 20 seeds m⁻¹.

ASSESSMENT OF GROWTH CHARACTERISTICS AND HYBRIDS PRODUCTION

Evaluations were carried out based on grain maturation stage, considering the dough stage reached at different times. The plant was cut manually using a machete (Tramontina®) at a height of 10 cm above the soil, disregarding the lateral lines (considered bordering area) and 0.5 m from the extremities of the two central rows. Plants from the usable area of each plot (2 central linear meters) were used for the evaluation of the following variables: number of tillers; plant height; percentages of leaf, stem, panicle, grain and dead ma-
The sorghum hybrids of double purpose were planted on November 15th, 2014, with harvesting and growing periods outlined as follows: hybrids 9929036, 9929030, 9929026 and 12F042226 were cut on march 2nd, 2015 with cycle of 105 days; hybrids 12F042224, 12F042150, FEPAGRO18, FEPAGRO19, FEPAGRO11, 9929012, 947216, 947030, 947072 and 947252 were cut on March 14th, 2015 with cycle of 119 days; hybrids 947254 and 12F042066 were cut on March 22nd, 2015 with cycle of 126 days; hybrids SF11, PROG134IPA, 1141570, 1141562 and BRS506 were cut on March 28th, 2015 with cycle of 132 days and hybrids SF15 and SF25 were cut on April 4th, 2015 with cycle of 138 days according to the phenological stage of the plant.

Number of tillers per linear meter was calculated based on the average of the total number of tillers in the usable plot area. Height was considered the average height of five plants chosen at random, measured with a steel measuring tape. The plants present within the usable area were harvested and weighed on a digital scale, which revealed the fresh mass.

For the morphological traits, two plants were collected from the usable plot area and separated into leaves, stems, dead mass and panicles, which were weighed individually to determine fresh weight. The samples were then dried in a forced-air oven at 55 °C for 72 h to determine the dry weight, as proposed by the Association of Official Analytical Chemists (AOAC) (1990).

**Multivariate analysis**

After collection, the data were stored in electronic spreadsheets for later analysis, using the statistical software SAS (Statistical Analysis System). The descriptive statistical analyses (mean, standard deviation and coefficient of variation) were performed through the MEANS procedure, the analysis of variance was performed by the PROC GLM and the means were compared using the Student Newman Keuls test at P<0.05, with clusters I, II and III showing the highest averages: 19.1, 20.5 and 15.4%, respectively, which is related to the morphological characteristics of these hybrids.

Cluster IV (947252) had the most productive hybrid regarding the yield of total green forage mass and total dry forage mass, presenting the following means 67.8 and 36.1 kg ha⁻¹. This was due to the hybrid present in this cluster which also presented the highest plant height: 234.8 cm, since the height of the sorghum is related to the productive characteristics (Table I). The production of forage sorghum hybrids can be altered by the handling adopted, in particular fertilization directly contributes to the increase in productivity and the agronomic characteristics of the plant (Nascimento et al., 2020 p.75). In this experiment, however, the handling was the same for all hybrids, the differences being attributed exclusively to genetic variation between plants and their interaction with the climate, mainly.

Considering a minimum threshold, three main components (CPs) (Table II) were responsible for an accumulation of about 67% of all phenotypic diversity observed among hybrids.

It was verified that the first main component formed by the agronomic characteristics total green forage mass, dry stem mass and total dry forage mass, explains 37% of the total variation, while the second main component formed by the agronomic characteristics of leaf / stem and mass grain dryness explains together with the first component an accumulated of 52%, and
the third main component formed by the lodging and dry mass characteristics of the leaf together with the other two components reached an accumulated 70% of expected variation (Table III). Demonstrating that there is a great variation between hybrids.

Since the principal component analysis analysis (MCA) is not correctly used for grouping, it was necessary a cluster analysis by the Ward method. The diversity verified with the principal component analysis analysis was confirmed by the cluster analysis by the Ward method, in which the most similar hybrids are grouped together (Figure 3).

The formation of the clusters took into account the sum of squares of the deviations of the observations in relation to the clusters formed by the hybrids.

In the similarity dendrogram (Figure 3) it was observed that there is variability between clusters, but within each cluster there is a similarity among individuals, however variability may exist indicating

Table I. Descriptive statistics of growth and production characteristics of 23 sorghum hybrids (Estatística descritiva das características de crescimento e produção de 23 híbridos de sorgo).

| Clusters | NT  | LODG | TGFM | TDFM | H    | L/S | DM      | LDM |
|----------|-----|------|------|------|------|-----|---------|-----|
|          | %   | Kg ha⁻¹ | cm  | t ha⁻¹ |      |     |         |     |
| Mean     | 19.1 a | 9.6 a | 29.6b | 11.4b | 148.0c | 0.1a | 4.0a    | 1.2a |
| I        | Maximum | 32.0 | 50.0 | 53.5 | 21.8 | 190.4 | 0.9 | 8.4 | 2.9 |
|          | Minimum | 11.0 | 0 | 14.4 | 5.2 | 94.6 | 0.09 | 0 | 0.4 |
|          | CV (%) | 30.2 | 168.0 | 47.1 | 50.7 | 24.5 | 38.7 | 77.7 | 64.6 |
|          | Mean   | 20.5 a | 17.3a | 42.7b | 17.4b | 181.4b | 0.2a | 5.1a | 2.2a |
| II       | Maximum | 25.0 | 54.5 | 58.4 | 25.0 | 211.6 | 0.3 | 10.6 | 4.5 |
|          | Minimum | 16.0 | 0 | 22.1 | 10.5 | 170.0 | 0.04 | 0.8 | 0.4 |
|          | CV (%) | 18.5 | 103.3 | 26.4 | 24.9 | 7.9 | 50.6 | 63.7 | 67.8 |
|          | Mean   | 15.4 a | 11.1a | 49.9b | 18.8b | 188.5b | 0.2a | 4.0a | 3.0 |
| III      | Maximum | 27.0 | 56.2 | 97.5 | 40.9 | 232.2 | 0.5 | 14.7 | 6.9a |
|          | Minimum | 8.0 | 0 | 15.6 | 6.0 | 140.0 | 0.1 | 0 | 0 |
|          | CV (%) | 22.0 | 118.4 | 39.5 | 41.7 | 12.3 | 35.3 | 75.2 | 52.0 |
|          | Mean   | 13.0b | 11.2a | 67.8a | 36.1a | 234.8a | 0.2a | 5.5a | 2.3 |
| IV       | Maximum | 15.0 | 13.3 | 71.7 | 36.4 | 247.8 | 0.3 | 5.7 | 4.6a |
|          | Minimum | 11.0 | 9.0 | 63.9 | 35.9 | 221.8 | 0.2 | 5.4 | 0 |
|          | CV (%) | 21.7 | 26.7 | 8.0 | 1.0 | 7.8 | 37.7 | 3.7 | 141.4 |

CV (%): Coefficient of Variation; NT: Number of Tillers; LODG: Lodging; TGFM: Total Green Forage Mass; TDFM: Total Dry Forage Mass; H: Height; L/S: leaf/stem ratio; DM: Dead Material; LDM: Leaf Dry Mass; SDM: Stem Dry Mass; DMDM: Dead Material Dry Mass; GDM: Grain Dry Mass. Means followed by equal letters in the column do not differ by the SNK test, at the significance level of 5%.

Figure 3. Dendrogram of grouping by the Ward’s method of the agronomic characteristics among the sorghum hybrids (Dendograma do agrupamento pelo método Ward das características agronômicas entre híbridos de sorgo forrageiro).
Table IV. Eigenvalues associated to the main components obtained from the agronomic characteristics between the sorghum hybrids (Autovalores associados aos componentes principais obtidos a partir das características agronômicas entre os híbridos de sorgo).

| Main Component | Eigenvalue | Difference between eigenvalues | Simple Variance | Cumulative Variation |
|----------------|------------|--------------------------------|-----------------|---------------------|
| 1              | 5.29       | 2.14                           | 0.33            | 0.33                |
| 2              | 3.16       | 0.76                           | 0.19            | 0.52                |
| 3              | 2.40       | 0.59                           | 0.15            | 0.67                |
| 4              | 1.80       | 0.13                           | 0.11            | 0.79                |
| 5              | 1.67       | 0.88                           | 0.10            | 0.89                |
| 6              | 0.79       | 0.45                           | 0.04            | 0.94                |
| 7              | 0.33       | 0.15                           | 0.02            | 0.96                |
| 8              | 0.21       | 0.08                           | 0.01            | 0.98                |
| 9              | 0.13       | 0.06                           | 0.00            | 0.98                |
| 10             | 0.07       | 0.02                           | 0.00            | 0.99                |
| 11             | 0.04       | 0.01                           | 0.00            | 0.99                |
| 12             | 0.03       | 0.01                           | 0.00            | 0.99                |
| 13             | 0.01       | 0.01                           | 0.00            | 0.99                |
| 14             | 0.00       | 0.00                           | 0.00            | 0.99                |
| 15             | 0.00       | 0.00                           | 0.00            | 1.00                |
| 16             | 0.00       | 0.00                           | 0.00            | 1.00                |

The dry matter production of sorghum cultivars is directly related to the plant height, as the highest cultivars reach greater productivity (Albuquerque et al. (2012, p.72). On the other hand, the yield of DM (t ha⁻¹) is a factor that is related to the management adopted and the productive capacity inherent to the species or hybrid (Table I).

According to Campana (2010, p.103), the variables of higher weights in the first eigenvectors are considered more important for the study of diversity, when the eigenvalue explains a considerable fraction of the available variation, usually limited to a minimum value of 70%. Also, it was observed that there was variability within the clusters, which may indicate that some hybrids may stand out for the agronomic characteristics (Table II). The edaphoclimatic conditions of the region in addition to precipitation and temperature (Figure 1) affected productivity, knowing that sorghum supports production in dry and low-fertility soils due to a greater conversion of water into dry matter (Silva et al., 2018 p .9). Thus, the hybrids that stood out were the most adapted to the climatic conditions of the region.

Principal component analysis also demonstrated that there is a wide variation between hybrids. This, in turn, implies that several characteristics were involved in explaining this variation. These results were similar to the values found by Castrillon et al. (2017) who worked with different agro-morphological characteristics in sorghum (Figure 2).

From the point of view of hybrid selection and identification, this variation is favorable, indicating that the hybrids are different from each other, with the possibility of comparison and selection of those that present desirable characteristics, whether productive, morphological or both (Ferreira et al., 2003, p.1563) (Table III). Cluster IV was less expressive, formed by only one genotype: 947252, suggesting that it was the most divergent of the total analyzed. According to Britez et al. (2011, p. 410) the occurrence of clusters with only one genotype shows wide divergence, since the hybrids in unit clusters are more dissimilar in relation to the set (Figure 3).

Figure 2. Dispersion plot based on the main components 1 versus the main components 2 of the agronomic characteristics of the sorghum hybrids (Trama de dispersão baseada nos principais componentes 1 versus os principais componentes 2 das características agronômicas dos híbridos de sorgo).
The characteristic total green forage mass (TGFM) (Table IV) is strongly correlated with the production of total dry forage mass (TDFM), as one increases the other also increases and therefore the hybrids that have stood out for TGFM, also obtained high rates of TDFM (Tardin et al., 2013, p.103). These correlations were also observed in other studies, emphasizing the importance of knowing associative effects in the selection of genetic materials with desirable characteristics for the production of silage in the semi-arid region, corroborating with the results obtained by Perazzo et al. (2014,p.232) that evaluated the agronomic characteristics of 32 sorghum cultivars in the Brazilian semi-arid region and observed that the dry matter yield was correlated with the green matter yield (r = 0.8754 **) and plant height (r = 0.61210 **) at 5% of significance, which is a good indicative since there is no need to wait for the plant to dry out to know the amount.

The high positive and strong correlation of leaf/stem ratio, leaf dry mass and stem dry mass with the production of green forage mass is related to plant growth. The dry matter yield was positively correlated with the percentage of stem in green and dry matter, (r=0.86) and 0.95, respectively, which may be related to the higher participation of this fraction in the plant. The differences found for these components indicate that the environmental factors, such as the amount and distribution of rain, temperature and soil, had a strong influence (Figure 1) with the reduced rainfall distribution (Jimmy et al., 2017, p.48). Therefore, these are key variables in the selection of genetic material with suitable properties for silage quality.

The percentages of leaves and stem have a strict connection with plant height, as higher sorghums present higher dry matter yield. However, due to the higher percentage of stems in comparison to leaves and panicles, the nutritional value of the forage may be compromised. Among the proportions of plant components, in the present study a positive correlation was found between stem and plant height (r = 0.63) (Carmo et al., 2020, p.424).

It was observed a positive and strong correlation between plant height and dry matter yield (r=0.61).

This higher dry matter yield, as well as the increased plant height, may be associated with the sensitivity of the sorghum to the photoperiod, causing greater elongation between the plant nodes.

Plants of average heights present a more balanced distribution of its components, which characterizes the double purpose sorghum (Cunha & Lima 2010, p.702).

**CONCLUSIONS**

There was genetic variability within the groups, indicating that some hybrids can be highlighted by agronomic characteristics (number of tillers number, lodging, total green forage mass, total dry forage mass, height, leaf/stem ratio, dead material, leaf dry mass) and thus group III (12F042224, FEPAGRO 11.9929012, 9929026, SF 25, 947216, 12F042150, 9929012, PROG 134 IPA) presented the hybrids more productive and more suitable for the production of silage in semi-arid regions, among the four groups.

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**Table IV. Correlation between the agronomic characteristics of the sorghum hybrids (Correlação entre as características agronômicas de híbridos de sorgo).**

|       | TGFM | TDFM | H   | L/S  | LDM | SDM | DMDM | GDM |
|-------|------|------|------|------|-----|-----|------|-----|
| TGFM  | 1.00 | <0.01| 0.01 | 0.01 | 0.60| 0.05| 0.03 | 0.43|
| TDFM  | 0.89 | 1.00 | <0.01| 0.29 | 0.01| 0.082| 0.01 | 0.75|
| H     | 0.61 | 0.65 | 1.00 | 0.29 | 0.01| 0.01 | 0.01 | 0.90|
| L/S   | 0.22 | 0.22 | 0.11 | 1.00 | 0.17| <0.01| 0.22 | 0.26|
| LDM   | 0.60 | 0.51 | 0.29 | 0.79 | 1.00| <0.01| 0.14 | 0.99|
| SDM   | 0.86 | 0.95 | 0.63 | 0.04 | 0.41| 1.00| <0.01| 0.62|
| DMDM  | 0.44 | 0.64 | 0.49 | 0.26 | 0.31| 0.56 | 1.00| <0.01|
| GDM   | 0.17 | 0.06 | -0.02| -0.35| -0.24| -0.01| -0.10| 1.00|

TGFM: Total Green Forage Mass; TDFM: Total Dry Forage Mass; H: Height; L/S: leaf/stem ratio; LDM: Leaf Dry Mass; SDM: Stem Dry Mass; DMDM: Dead Material Dry Mass; GDM: Grain Dry Mass.
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