**Características agronômicas e eficiência do uso da chuva do sorgo em região semiárida**

**Agronomic characteristics and rain use efficiency of sorghum in a semiarid region**

**Características agronómicas y eficiencia del uso de la lluvia de sorgo en una región semiárida**

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**Resumo**

A cultura do sorgo se destaca na nutrição animal por possibilitar seu cultivo para conservação verde como silagem. Objetivou-se avaliar a divergência das características agronômicas e produtivas de 32 cultivares de sorgo na região Semiárida. O delineamento adotado foi em blocos casualizados com três repetições. Avaliou-se: concentração de matéria seca (DM), produção de matéria verde (FMP) e seca (DMP) em kg ha$^{-1}$; proporção de colmo, panícula e lâmina foliar na MS da planta; altura da planta, número de plantas ha$^{-1}$, diâmetro de colmo, número de folhas, tamanho de folhas e de panículas; eficiência do uso da chuva (RUE) em kg MS ha$^{-1}$ mm$^{-1}$ e acúmulo de água (WA) em kg ha$^{-1}$ e kg ha$^{-1}$ mm$^{-1}$. Os dados foram analisados pelo procedimento Scott-Knott ao nível 5% de significância. As FMP e DMP apresentaram formação de dois grupos distintos, que podem ser cruciais na escolha de uma cultivar mais produtiva. A cultivar 17 se destacou por apresentar uma alta participação de lâmina foliar e as cultivares 9, 19, 23, 24 e 32 na participação de panícula na DM, que são nutricionalmente importante devido à maior digestibilidade que o colmo. Para RUE e WA também foram formados dois grupos distintos, que podem ser importantes para determinar cultivares que apresentem potencial xerófilo superior, e assim utilizá-los para produção de silagem em condição semiárida. Pesquisas que avaliem o desempenho animal com as cultivares 3, 6, 9, 17, 19 e 31 podem ser conduzidos para comprovar o valor nutritivo dessas culturas, já que estas se destacaram por apresentar características produtivas e de adaptabilidade interessantes.

**Palavras-chave:** Forragem; matéria seca; panícula.

**Abstract**

Sorghum culture highlighted in animal nutrition because it allows its cultivation of green conservation as silage. This study aimed to evaluate the divergence of agronomic and productive characteristics of 32 sorghum cultivars in the semiarid region. The randomized block design with three replications was used. It was evaluated the dry matter percentage (DM), fresh matter production (FMP) and dry matter production (DMP); stem proportion,

panicle, and leaf blade in the plant DM; plant height, nº plants ha$^{-1}$, stem diameter, leaf number, leaves and panicles length; rain use efficiency (RUE) in kg MS ha$^{-1}$ mm$^{-1}$, and water accumulation (WA) in kg ha$^{-1}$ and kg ha$^{-1}$ mm$^{-1}$. The data were analyzed using the Scott-Knott procedure at a 5% significance level. The FMP and DMP showed the formation of two distinct groups, which may be crucial in choosing a more productive cultivar. Moreover, cultivar 17 stood out for presenting high leaf blade participation while cultivars 9, 19, 23, 24, and 32 in panicle participation in DM, which is considered nutritionally better due to higher digestibility than the stem. Besides, for the RUE and WA, two distinct groups were also formed, which can be great to determine cultivars that have higher xerophilic potential, and thus use them for the production of silage in semi-arid conditions. Experimental cultivars showed greater results than those commercials. Studies that evaluate the animal performance of cultivars (3, 6, 9, 17, 19, and 31), could be conducted to prove their nutritional values since these cultivars stood out for presenting interesting productive characteristics.

**Keywords:** Dry matter; forage; panicle.

**Resumen**

El cultivo del sorgo se destaca en la nutrición animal porque permite su cultivo para la conservación verde como ensilaje. El objetivo fue evaluar la divergencia de las características agronómicas y productivas de 32 cultivares de sorgo en la región semiárida. El diseño adoptado fue en bloques al azar con tres repeticiones. Se evaluó: concentración de materia seca (DM), producción verde (FMP) y seca (DMP) en kg ha$^{-1}$; proporción de tallo, panícula y lámina de la hoja en la planta DM; altura de la planta, número de plantas ha$^{-1}$, diámetro del tallo, número de hojas, tamaño de hojas y panículas; eficiencia del uso de lluvia (RUE) en kg MS ha$^{-1}$ mm$^{-1}$ y acumulación de agua (WA) en kg ha$^{-1}$ y kg ha$^{-1}$ mm$^{-1}$. Los datos se analizaron mediante el procedimiento de Scott-Knott a un nivel de significación del 5%. El FMP y el DMP mostraron la formación de dos grupos distintos, que pueden ser cruciales para elegir un cultivar más productivo. El cultivar 17 se destacó por presentar una gran proporción de la lámina de la hoja y los cultivares 9, 19, 23, 24 y 32 en la participación de la panícula en la DM, que son nutricionalmente importantes debido a la mayor digestibilidad que el tallo. Para los RUE y WA también se formaron dos grupos distintos, que pueden ser importantes para determinar cultivares que tengan un potencial xerofílico superior y, por lo tanto, usarlos para la producción de ensilaje en condiciones semiáridas. Se pueden realizar investigaciones que evalúen el rendimiento de los animales con los cultivares 3, 6, 9, 17, 19 y 31 para probar el

valor nutricional de estos cultivos, ya que se destacaron por presentar interesantes características productivas y de adaptabilidad.

**Palabras clave:** Forraje; materia seca; panícula.

## 1. Introduction

The Brazilian semiarid region is characterized by its irregular rainfall distribution and frequent occurrence of prolonged droughts, with shallow soils, stony, and low fertility, it makes fodder production a challenge for animal production in the region. Based on this information, it is necessary to adopt forage crops that are efficient in the use of water resources available in the region.

Sorghum (*Sorghum bicolo*r (L). Moench) is a crop that may be compared to corn concerning its nutrition and agronomic values. In terms of requirements and production, it is an interesting alternative for semi-arid regions because it is more adapted to the local edaphoclimatic conditions, with the capacity for productive recovery of biomass and grains after a drought period. According to Sawargaonkar et al. (2013), sorghum has high levels of fermentable sugars, low demand for fertilizers, short growth period, high water use efficiency, and the ability to adapt well to various climate and soil conditions. Therefore, its adoption as grass for future silage production is an increasingly frequent activity by rural producers in these regions, since it has a lower production cost than corn.

The increase in demand on this crop by producers favors the improvement of sorghum varieties resulting in the appearance of several cultivars and hybrids over the world. Generally these commercialized genotypes are divided according to their productive potential and aptitude, presenting selections not only for greater accumulations of green biomass (silage production) but also improved cultivars for dual purposes (grain and silage production) and specifically for the production of grains (Qiu, Yadav & Yin, 2017).

Comparative studies of the cultivars formed are therefore used and essential to determine the productive potential, the efficiency in the use of water and the nutritional quality, facilitating the understanding, trade and genetic improvement of the culture (Perazzo et al., 2017). In addition, these competition tests are of great importance; through them, it is possible to explore the full plant potential in a given environment. Cultivars differ by plant height, amounts of stem, leaves, and panicles, which reflects in productivity, chemical composition, and nutritional value. Given the above, this study aimed to assess the divergence of agronomic and productive characteristics of 32 sorghum cultivars in the Semi-arid region.

## 2. Material and Methods

### 2.1 Location and treatments

A research aims to reach a new knowledge. In this study an field research was carried out with descriptive data of the quali-quantitative type and with the premise of obtaining new knowledge for the society (Pereira et al., 2018). The experiment was conducted at the Pendência Experimental Station, of the Paraiba Research Company, Rural Extension and Land Regularization (EMPAER-PB), located in the municipality of Soledade, Paraíba state, Brazil (Coordinates 7º 8' South and 36º 27' West, and altitude of 534 m asl). Based on the Köppen classification, the climatic type of the region is predominantly Bsh (hot semi-arid), with rains from January to April, average annual temperatures around 24 ºC, relative air humidity around 68%, an average rainfall of 400 mm per year, with water deficit for almost year-round.

The experimental design used was set up in randomized blocks with three replications. The experimental treatments were 32 sorghum cultivars developed by the breeding program of the Agricultural Research Institute of Pernambuco - IPA.

The following cultivars were evaluated, identified by numerical order:: SF-25 (Cultivar 1), 02-03-01 (Cultivar 2), 43-70-02 (Cultivar 3), 10-Ca84-B2Ca87-B2SB88-BCa89 (Cultivar 4), 25-Ca84-B2Ca87-B1SB88-BCa89 (Cultivar 5), 38-Ca84-B2Ca87-B2SB88-BCa89 (Cultivar 6), 41-Ca84-BCa87-B1SB88-BCa89 (Cultivar 7), 41-Ca84-BCa87-B2SB88-BCa89 (Cultivar 8), 46-Ca84-B2Ca87-B2SB88-BCa89 (Cultivar 9), 68-Ca84-BCa87-01SB88-01SB89 (Cultivar 10), SF 11 (Cultivar 11), 18-Ca84-B1Ca87-SB88B-Ca89 (Cultivar 12), 24Ca84-B1Ca87-B2SB88-BCa89 (Cultivar 13), 25Ca84-B1Ca87-B1SB88-BCa89 (Cultivar 14), 25Ca84-B2Ca87-B1SB88-BCa89 (Cultivar 15), 41Ca84-BCa87-B1SB88-BCa89 (Cultivar 16), 52Ca84-BCa87-B1SB88-BCa89 (Cultivar 17), 63Ca84-B1Ca87-B2SB88-BCa89 (Cultivar 18), 80Ca84-01Ca87-B1SB88-BCa89 (Cultivar 19), ST87-18, ST88-01, ST89-01 (Cultivar 20), Forager black (Cultivar 21), Chocolate Forager (Cultivar 22), Forager thesis - 25 (Cultivar 23), Forager thesis - 33 (Cultivar 24), Red Forager (Cultivar 25), T6 (467-4-2 R1) (Cultivar 26), T14 (02-03-01 R1) (Cultivar 27), T34 (Sudan 4202 R1) (Cultivar 28), Ponta Negra (Cultivar 29), Red Sorghum - Araripina (Cultivar 30),  SF 15 (Cultivar 31) and IPA 2502 (Cultivar 32).

**2.2 Harverst and variables analysed**

The sorghum cultivars were manually sown on March 5, 2011, in plots of 8.4 m² (4.2 x 2.0), with a spacing of 70 cm between rows. Thinning has been done 30 days after planting to maintain 12 plants per linear meter. Fertilization was made based on the chemical attributes of the soil in the experimental area using 50 kg of nitrogen, in the form of ammonium sulfate, 15 days after sowing (Table 1).

**Table 1 -** Soil chemical attributes of the experimental area.

| pH in $H_2O$ | P | $K^+$ | Na | $H^++Al^{+3}$ | $Al^{+3}$ | $Ca^{+2}$ | $Mg^{+2}$ | SB | CEC | V | O.M. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ----mg/dm³---- | | | -----------------------cmolc/dm³--------------------- | | | | | | % | g/kg |
| 6.0 | 13.49 | 187.67 | 0.0 | 2.80 | 0.00 | 5.00 | 1.60 | 7.08 | 9.88 | 71.66 | 8.23 |

P - phosphorus; $K^+$ - potassium; $Na^+$ - sodium; $H^++Al^{+3}$ - potential acidity; $Al^{+3}$ - aluminum; $Ca^{+2}$ – calcium; $Mg^{+2}$ - magnesium; V% - saturation/base; CEC = cation exchange capacity; OM - organic matter; SB - sum of bases.

Harvesting has carried out when the grains were in the pasty/farinaceous stage. Due to the experimental cultivars reached the harvest point on different days, two harvests were taken. The duration of the cycle from planting to harvest was 78 and 88 days for the first and second harvest, respectively. In the first, the cultivars were harvested: 4, 14, 18, 23, 24, 26, 27, 28, 29, 30, and 32. While, in the second, the cultivars: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 15, 16, 17, 19, 20, 21, 22, 25, and 31 were collected. The assessment cut was made manually with cleavers. To the assessment, the production of two meters of furrow per plot were considered, initially counting the number of tillers per linear meter.

Accumulated Total Precipitation in the first and second harvest was 578 and 609.8 mm, respectively. The assessment cut was made 10 cm above the ground. Also, it was evaluated the production of 2 m from the centerline. The evaluated characteristics were: number of tillers ha$^{-1}$, leaf number , plant height, stem diameter, leaf length , panicle length, fresh matter production (FMP)  and dry matter production (DMP) in kg ha$^{-1}$, proportion of dry matter components, panicle, leaf blades and stem, and rain water use efficiency (WUE) and water accumulation (WAC). The material collected from each plot was separated into a panicle, leaf blade, and stem, each fraction being weighed separately, placed in identified, weighed bags and oven-dried for 72 hours in a forced ventilation at 55°C, and then weighed to determine the proportion of plant parts on a dry matter basis. The variables: plant height, stem diameter, leaf length, panicle length were measured with a measuring tape and digital caliper.

Fresh matter production per hectare was obtained by the product between the production per cultivated linear meter and the total cultivated linear meters per hectare. Dry matter production was estimated by the product between green matter production and dry matter content and was expressed as dry matter production per hectare.

After initial weighing of the collected material, it was oven-dried at 55°C for 72 hours, and then weighed to obtain the dry matter values. Furthermore, the plant population density per hectare was estimated by the number of tillers per cultivated linear meter and a total of linear meters per hectare.

Rain use efficiency (WUE) was estimated by dividing the dry matter weight by the amount of water accumulated during the cycle (Ertek, Sensoy, and Gedik 2006). Concerning WAC, this was represented in kg ha$^{-1}$ by subtracting FMP from DMP, being its result divided by the observed precipitation for the productive cycle of the cultivar. The unit used for its determination was in kg ha$^{-1}$ mm$^{-1}$.

## 2.3. Statistical analyses

The results obtained were submitted at variance analysis. When there was a significant difference, the Scott-Knott test was used at a 5% level of probability to compare the means of each cut treatment. The SAS (2002) software (SAS Inst. Inc., Cary, NC, USA) was used.

## 3. Results and Discussion

Effect ($P < 0.050$) of cultivars was observed for the FMP, which showed the formation of two groups, the first, more productive that exhibited a FMP greater than 54.075 kg ha$^{-1}$, and the second group, least productive with FMP ranging from 34.979 to 51.258 kg ha$^{-1}$. General average for all cultivars was 56.023 kg ha$^{-1}$ (Table 2).

**Table 2** - Mean values of fresh matter production (FMP), dry matter production (DMP), and dry matter content (DM) of thirty-two sorghum cultivars in a semiarid region.

| Cultivars | FMP (kg ha$^{-1}$) | DMP (kg ha$^{-1}$) | DM g kg$^{-1}$ |
|---|---|---|---|
| Cultivar 1 | 51.258b | 9.642b | 200.5b |
| Cultivar 2 | 60.297a | 11.790b | 193.9b |
| Cultivar 3 | 68.808a | 21.952a | 322.7a |
| Cultivar 4 | 49.520b | 12.000b | 244.8b |
| Cultivar 5 | 58.714a | 16.639a | 287.7a |
| Cultivar 6 | 72.356a | 22.943a | 318.4a |
| Cultivar 7 | 72.620a | 17.470a | 240.9b |
| Cultivar 8 | 60.908a | 17.136a | 280.1a |
| Cultivar 9 | 61.543a | 17.751a | 288.7a |
| Cultivar 10 | 34.979b | 11.084b | 324.4a |
| Cultivar 11 | 55.974a | 15.474a | 269.8b |
| Cultivar 12 | 57.444a | 17.224a | 302.1a |
| Cultivar 13 | 71.925a | 17.154a | 236.9b |
| Cultivar 14 | 57.420a | 13.783b | 241.0b |
| Cultivar 15 | 63.006a | 16.524a | 263.4b |
| Cultivar 16 | 73.747a | 18.916a | 256.1b |
| Cultivar 17 | 62.982a | 18.109a | 288.9a |
| Cultivar 18 | 48.153b | 14.106b | 293.6a |
| Cultivar 19 | 48.165b | 16.017a | 332.5a |
| Cultivar 20 | 54.075a | 12.816b | 236.3b |
| Cultivar 21 | 62.275a | 17.334a | 275.3a |
| Cultivar 22 | 59.589a | 18.959a | 320.5a |
| Cultivar 23 | 42.167b | 10.863b | 262.4b |
| Cultivar 24 | 43.622b | 10.905b | 250.0b |
| Cultivar 25 | 68.112a | 14.973a | 219.8b |
| Cultivar 26 | 61.316a | 16.228a | 265.3b |
| Cultivar 27 | 48.906b | 10.915b | 224.3b |
| Cultivar 28 | 45.720b | 12.001b | 261.9b |
| Cultivar 29 | 37.065b | 8.976b | 241.5b |
| Cultivar 30 | 42.867b | 11.533b | 270.1b |
| Cultivar 31 | 60.129a | 15.852a | 263.2b |
| Cultivar 32 | 37.089b | 8.828b | 238.9b |
| S.E.M | 1281.94 | 372.18 | 0.397 |
| General Average | 56.023 | 14.872 | 26.61 |

Means followed by different letters in the column differ by the Scott Knott test ($P < 0.05$). S.E.M., standard error of mean. Source: Authors

Studies conducted by Silva et al. (2011), and Cunha & Lima (2010) showed lower FMP than those found (Table 2), with means of 35.70 and 46.777 kg ha$^{-1}$, respectively for different forage sorghum genotypes. The lower production found in these surveys is probably due to the less rainfall reported in these experiments.

Santos et al. (2013) observed an average FMP of 67.600 kg ha$^{-1}$ for five cultivars of forage sorghum in Sub-Medium Sao Francisco Valley. Almeida et al. (2019) found average results far above to the presented in this study when evaluating sorghum biomass hybrids for ethanol production, grown in two cities in the Minas Gerais state that had an average FMP of 96.718 kg ha$^{-1}$. These favorable results probably occurred due to the high rainfall reported in comparisons with those presented in semiarid locations, in addition to biomass sorghum hybrids having a longer vegetative period (photoperiod sensitivity), high leaf area index and interception, and radiation use efficiency (metabolism C$_4$) (Olson et al., 2012).

DMP results also showed the formation of two groups ($P < 0.050$). The less productive range from 8.828 to 14.106 kg ha$^{-1}$ and the more productive group present values above 14.973 kg ha$^{-1}$. Added emphasis needs to be placed to cultivars 3 (43-70-02) and 6 (38-Ca84-B2Ca87-B2SB88-BCa89), that had a DMP higher than 20.000 kg ha$^{-1}$. Furthermore, in the present research the DMP showed a positive correlation with FMP ($r = 0.87$), plant height ($r = 0.61$) and number of tillers ($r = 0.57$) (Perazzo et al., 2014), which directly influenced this variable. Gomes, Pitombeira, Neiva & Cândido (2006) reported a direct relationship between plant height and DMP when analyzing the agronomic and bromatological behavior of different forage sorghum cultivars in Ceará state, Brazil.

Furthermore, the general average observed for DMP was 14.872 kg ha$^{-1}$, presenting similar results to those found in the research conducted by Silva et al. (2011) and Cunha & Lima (2010). Moraes, Jobim, Silva & Marquardt (2013) evaluating three dual-purpose hybrids and a forage, found FMP variable between 9.778 and 12.767 kg ha$^{-1}$. On the other hand, although Botelho et al. (2010) in their research found a lower mean for FMP (47.390 kg ha$^{-1}$) compared to the present study, they also showed higher values for DMP (15.340 kg ha$^{-1}$), due to the evaluated genotypes presenting a higher dry matter percentage in its composition. Similarly, the research carried out by Bean, Baumhardt, McCollum III & McCuistion (2013), showed an average of 16.230 kg ha$^{-1}$ for 27 cultivars of different purposes and their use in four consecutive years for the production of grains or forage. For forage sorghum, the specific average was 17.100 kg ha$^{-1}$.

DMP and FMP are practically the most observed and relevant characteristics to farmers at the time of seeds and cuttings purchased since they reflect the achieved productivity by specific cultivar, hybrid, or genotype, being generally selected varieties that present better biomass gains and consequently, enhancing the animal productivity. Results observed for these variables demonstrate the potential of cultivars developed in semiarid

conditions when they reach productivity equal to or greater than hybrids, that are developed to exhibit high productive potential.

For DM content, cultivars 3, 5, 6, 8, 9, 10, 12, 17, 18, 19, 21 and 22 had the highest concentrations (variations from 332.5 to 275.3 g kg$^{-1}$) and the others cultivars the lowest (193.9 to 270.1 g kg$^{-1}$), forming two different groups ($P < 0.050$) and presenting a general average for cultivars studied at 266.1 g kg$^{-1}$ (Table 2).

DM content in the plant is a relevant factor, mainly during the fermentation process in the silages production since it is a factor that directly influences the fermentation type developed in the silo. The optimum concentration for harvesting is between 300.0 to 350.0 g kg$^{-1}$ of DM that indicates the stage of soft mass (Vendramini, Adesogan & Wasdin, 2009). Among all cultivars studied, only six (nº 3, 6, 10, 12, 19, and 22) had adequate DM concentrations (Table 2). The other cultivars require more attention in cultivation, aiming at the silage process. However, if the material to be ensiled has sufficient concentrations of soluble carbohydrates, the presence of DM concentrations above 200.0 g kg$^{-1}$ might well be enough to guarantee adequate fermentation and conservation of the mass (McDonald, Henderson & Heron, 1991). Besides, cultivars with contestable DM levels can be ensiled with additives to regulate moisture concentration.

Bean et al. (2013) found higher average concentrations (327.2 g kg$^{-1}$) for 27 cultivars of different purposes. The authors found that generally, grain cultivars (415.0 g kg$^{-1}$) have a higher DM content than forage sorghum/biomass/silage cultivars (309.6 g kg$^{-1}$) because they have fewer panicles participation in the composition. In this study, the significant presence of cultivars for silage production may have been essential to compromise this general average of DM percentage.

Regarding the participative proportion of the culture components, among the evaluated cultivars, the number 17 (52.Ca84-BCa87-B1SB88-BCa89) stood out ($P < 0.050$) with the highest content participation for leaf blade with 480.3 g/kg for DM (Table 3). The other 31 cultivars had similar values ($P < 0.050$), although with variations from 54.8 to 213.6 g kg$^{-1}$. The general average obtained for the leaf blade percentage was 131.3 g kg$^{-1}$.

**Table 3** - Mean values of the leaf blade, panicle, and stem based on dry matter (g/kg), and average height in meters, of thirty-two sorghum cultivars in a semi-arid region.

| Cultivars | Leaf Blade | Panicle | Stem | Plant Height |
|---|---|---|---|---|
| Cultivar 1 | 113.3b | 76.7b | 809.9a | 3.73b |
| Cultivar 2 | 82.8b | 48.9b | 868.3a | 3.43b |
| Cultivar 3 | 136.2b | 66.6b | 797.2a | 4.14a |
| Cultivar 4 | 54.8b | 143.4b | 801.7a | 3.95a |
| Cultivar 5 | 101.4b | 60.5b | 838.2a | 4.16a |
| Cultivar 6 | 111.1b | 46.8b | 842.2a | 4.09a |
| Cultivar 7 | 862.0b | 50.5b | 863.3a | 3.96a |
| Cultivar 8 | 145.3b | 53.7b | 801.0a | 4.10a |
| Cultivar 9 | 197.2b | 277.4a | 525.4b | 3.77b |
| Cultivar 10 | 149.6b | 118.3b | 732.2a | 2.91c |
| Cultivar 11 | 151.4b | 32.6b | 816.0a | 3.84a |
| Cultivar 12 | 119.2b | 74.8b | 806.0a | 3.59b |
| Cultivar 13 | 98.6b | 51.9b | 849.6a | 3.79b |
| Cultivar 14 | 199.3b | 78.4b | 722.2a | 3.29b |
| Cultivar 15 | 121.5b | 24.9b | 853.6a | 4.16a |
| Cultivar 16 | 80.8b | 42.8b | 876.3a | 4.01a |
| Cultivar 17 | 480.3a | 142.9b | 376.8b | 3.89a |
| Cultivar 18 | 183.1b | 67.9b | 748.9a | 3.63b |
| Cultivar 19 | 88.1b | 240.9a | 671.0a | 4.16a |
| Cultivar 20 | 103.9b | 101.4b | 794.6a | 3.12c |
| Cultivar 21 | 99.2b | 90.1b | 810.7a | 3.27b |
| Cultivar 22 | 154.1b | 63.0b | 782.9a | 4.09a |
| Cultivar 23 | 101.8b | 187.6a | 710.5a | 2.48d |
| Cultivar 24 | 94.9b | 279.9a | 625.1a | 3.14c |
| Cultivar 25 | 82.5b | 61.0b | 856.4a | 3.70b |
| Cultivar 26 | 137.1b | 129.5b | 733.3a | 3.44b |
| Cultivar 27 | 105.8b | 79.2b | 814.9a | 2.10e |
| Cultivar 28 | 113.6b | 93.4b | 792.9a | 3.11c |
| Cultivar 29 | 100.4b | 68.9b | 830.7a | 1.91e |
| Cultivar 30 | 74.5b | 108.7b | 816.8a | 2.96c |
| Cultivar 31 | 213.6b | 67.5b | 718.9b | 4.02a |
| Cultivar 32 | 119.9b | 213.9a | 666.2a | 1.76e |
| S.E.M | 0.870 | 0.963 | 1.295 | 0.16 |
| General Average | 13.13 | 10.14 | 75.69 | 3.49 |

Means followed by different letters in the column differ by the Scott Knott test ($P < 0.05$). S.E.M., standard error of mean. Source: Authors

The cultivar with the highest content for leaf blade (number 17) was practically identical to that found by Moraes et al. (2013) for the dual-purpose cultivar XBS 60451, which presented an average of 487.6 g kg$^{-1}$. At the same time, the general average obtained (Table 3) being similar to those reported by Jacovetti et al. (2018) in comparison of different grasses for silage that found an average of 144.0 g kg$^{-1}$ for sorghum.

Regarding the proportion of panicles, two distinct groups were formed ($P < 0.050$). In one group, the average obtained was 75.7 g kg$^{-1}$, while the other group was 239.9 g kg$^{-1}$, represented by cultivars 9, 19, 23, 24, and 32. Between that cultivars with a higher proportion of panicle, the cultivar 32 (IPA 2502) has already been marketed for grains and silages production. As most of the cultivars studied were improved for silage production, the panicles percentage tended to be smaller among the three studied components of the culture. Nonetheless, those cultivars probably show improvement for dual-purposes.

Moreover, it was observed that commercial cultivars (No. 29, 30, 31, and 32) obtained panicles percentage corresponding to their selection purposes, being improved for silage production except cultivar 32, already mentioned for dual-purpose. Nevertheless, Perazzo et al. (2013) reported higher percentages for the same four cultivars; however, the cultivar's height was significantly lower, inducing less stem participation and greater to panicle and leaf blade, contrary to what was observed in the present study.

Cultivars also formed two groups ($P < 0.050$) for the stem proportion variable. The first reached an average of 429.2 g kg$^{-1}$ (cultivars 9, 17, and 31) while the second group, formed by the other cultivars, getting 790.7 g kg$^{-1}$. The general average was 756.9 g kg$^{-1}$.

Considering the general average of stem content in DM, Meki et al. (2017) reported a close average (730.0 g kg$^{-1}$), in a study with commercial biomass sorghum hybrids (Integra 405 and Integra 1990) in Hawaii and Texas, USA.

It is observed that most of the cultivars showed high stem participation in the DM, having a positive correlation with the plant height ($r = 0.36$), which are consequences of the foraging behavior of the cultivars. Also, some researchers reported that the greater cultivars and cutting time, the smaller the participation of leaves (Atis, Konuskan, Duru, Gozubenli & Yilmaz, 2012). However, a high stem percentage about leaf blades and panicle may compromise the nutritional value of the culture, mainly due to the leaves and panicle presenting the highest digestibility coefficients (Jacovetti et al., 2018). The high stem concentration found in most cultivars also induces greater water retention, directly influencing the observed DM concentration (Table 2), which, as already reported, also has significant importance for the culture ensiling process.

Paraíso et al. (2017) studying the agronomic characteristics of six forage sorghum hybrids found an average proportion of 516.9, 332.2, and 150.9 g kg$^{-1}$ for stem, leaves, and panicle, respectively. However, Pannacci & Bartolini (2016) reported differences for hybrids only for leaf blades. These authors found an average content partition for stalk, leaves, and

panicle of 703.0, 166.0, and 131.0 g kg$^{-1}$, and 736.0, 157.0, and 107.0 g kg$^{-1}$ for three forage sorghum hybrids and three biomass sorghum hybrids, respectively.

Difference ($P < 0.050$) was found for plant height (PH) among the cultivars, with the formation of five groups. The group with the greatest heights ranged from 3.84 to 4.16 m, whereas the group with the lowest heights ranged from 1.76 to 2.10 m. The current research exhibited general variations from 1.76 to 4.16 m to the cultivars.

The variation observed in PH (Table 3), highlights the different aptitudes of the studied cultivars, with some improvements to show a high and continuous growth influencing the increase in biomass due to the higher stem percentage and leaf blade. Other varieties that reach the cutting time with smaller heights and a higher panicles percentage characterized a dual-purpose behavior (Perazzo et al., 2013). Almeida et al. (2019) presented an average height of 4.17 m for six biomass sorghum hybrids developed by the Embrapa maize and Sorghum Improvement Program. Similarly, Silva et al. (2018) also found an average higher than present work, with thirty sorghum biomass hybrids in the city of Sete Lagoas that presented an average of 4.49 m. Generally, hybrids have higher plant height concerning cultivars/genotypes, as they have hybrid/heterosis vigor, being this the increase in vigor found in an F1 in relation to its parents (Castro et al., 2015).

However, in research carried out by Fortes, Evaristo, Barros & Pimentel (2018), with cultivars aimed at silage production, was found the general average value (3.05 m) lower than those presented in this study (3.49 m). The same can be observed in the study conducted by Botelho et al. (2010) with sorghum genotypes for silage production, which found an average height of 2.23 m for the first cut. However, Cunha & Lima (2010), evaluating 29 forage sorghum cultivars, most of them similar to the ones in the present study, found a general average of 3.20 m.

Thus, it is evidenced that the cultivars evaluated in the currently research have considerable biomass production potential because they reach the reproductive period later, with greater height and, consequently, greater FMP.

The number of tillers ha$^{-1}$ (NT) was divided into 3 groups and was observe a high variation from 74.324.66 to 230.059 (Table 4).

**Table 4** - Mean values for number of tillers per hectare (NT), stem diameter (SD), leaf number (LN), average leaves length (LL) and panicle length (PZ) of thirty-two sorghum cultivars in a semiarid region.

| Cultivars | No. tillers ha^{-1} | Stem diameter | Leaf number | Leaf length | Panicle length |
|---|---|---|---|---|---|
| Cultivar 1 | 173.977a | 1.78b | 11.17a | 75.37a | 33.33b |
| Cultivar 2 | 137.193b | 1.70b | 11.00a | 61.54b | 25.33c |
| Cultivar 3 | 230.059a | 1.88a | 11.50a | 79.88a | 39.67a |
| Cultivar 4 | 163.041a | 1.78b | 11.50a | 75.20a | 32.00b |
| Cultivar 5 | 152.749a | 1.95a | 10.50a | 67.07b | 34.00b |
| Cultivar 6 | 191.696a | 1.88a | 11.17a | 68.10b | 31.67b |
| Cultivar 7 | 148.363b | 1.25c | 10.83a | 62.39b | 32.67b |
| Cultivar 8 | 160.644a | 1.93a | 11.33a | 88.42a | 33.17b |
| Cultivar 9 | 139.182b | 2.15a | 10.67a | 76.67a | 31.67b |
| Cultivar 10 | 129.747b | 1.78b | 10.67a | 64.67b | 23.83c |
| Cultivar 11 | 136.784b | 2.30a | 11.00a | 84.88a | 28.00c |
| Cultivar 12 | 182.223a | 1.95a | 11.17a | 70.05b | 29.83b |
| Cultivar 13 | 160.644a | 1.93a | 11.17a | 67.61b | 29.00c |
| Cultivar 14 | 172.632a | 2.06a | 12.00a | 77.28a | 24.83c |
| Cultivar 15 | 179.825a | 2.03a | 11.67a | 61.72b | 32.17b |
| Cultivar 16 | 153.451a | 1.77b | 10.83a | 82.19a | 30.17b |
| Cultivar 17 | 143.860b | 1.93a | 10.67a | 76.21a | 31.83b |
| Cultivar 18 | 201.404a | 1.43c | 10.67a | 70.21b | 28.50c |
| Cultivar 19 | 136.667b | 1.73b | 10.17a | 79.30a | 40.50a |
| Cultivar 20 | 170.234a | 1.63b | 8.33b | 76.08a | 33.33c |
| Cultivar 21 | 141.462b | 1.58b | 9.00b | 60.21b | 23.67c |
| Cultivar 22 | 204.620a | 1.72b | 10.67a | 82.43a | 33.00b |
| Cultivar 23 | 194.211a | 1.00c | 7.00c | 55.89b | 33.33b |
| Cultivar 24 | 175.632a | 1.52b | 7.33c | 63.67b | 28.33c |
| Cultivar 25 | 172.623a | 1.73b | 9.00b | 68.17b | 25.67c |
| Cultivar 26 | 160.644a | 1.70b | 8.67b | 71.17a | 34.33b |
| Cultivar 27 | 103.099c | 2.23a | 11.00a | 66.90b | 30.67b |
| Cultivar 28 | 190.644a | 1.82b | 8.50b | 59.83b | 33.17b |
| Cultivar 29 | 74.328c | 2.27a | 10.00a | 71.50a | 30.50b |
| Cultivar 30 | 91.111c | 1.43c | 9.00b | 52.75b | 15.33d |
| Cultivar 31 | 155.848a | 2.03a | 11.33a | 72.15a | 36.83a |
| Cultivar 32 | 79.123c | 2.23a | 8.17b | 73.47a | 34.50b |
| S.E.M | 15933.75 | 0.15 | 0.48 | 5.45 | 1.76 |
| General Average | 156.490 | 1.82 | 10.24 | 70.72 | 30.77 |

Means followed by different letters in the column differ by the Scott Knott test ($P < 0.05$). S.E.M., standard error of mean. Source: Authors

The average of NT (156.490, in Table 4), values close to the results found by Botelho et al. (2010) for four sorghum genotypes, who got the averaged of 161.070 NT. However, the results by Santos et al. (2013) proved to be superior, with an average of 174.317 NT, which probably induced higher GMP and DMP than those found in the present study. Silva et al.

(2016), in a study with 33 cultivars of sorghum biomass and forage, reported a lower proportion (104.607 NT), however, they had greater FMP and DMP due to the cultivars having higher heights. As already mentioned, this variable and the PH showed an positive influence on DMP, emphasizing the importance of the knowledge and explanation of these associative effects to choose genetic materials with desirable characteristics for the production of silage.

Cultivars 27, 29, 30, and 32 showed the lowest values. This variable had an general average of 156.490 NT. For the stem diameter (SD), it was possible to observe the formation of up to three groups ($P < 0.050$) with variation between 1.00 to 2.30 cm and an average of 1.82 cm. The cultivars 7, 18, 23 and 30 showed the lowest values (1.00, 1.25, 1.43 and 1.43 respectively).

The SD is important for assessing possible resistance to lodging of plants, occurring predominantly in cultivars that have high height and thin stems, since these are more exposed to the force of the winds and do not have considerable support, being a problem in regions with strong winds and thunderstorms. Fortes et al. (2018) confirm this evidence when observing that the percentage of bedridden plants was higher in those with lower SD, with the cultivars evaluated averaging 1.88 cm in diameter. Therefore, greater attention should be given to cultivars that were located in the group with the lowest observed diameter (No. 7, 18, 23, and 30), which may induce lodging.

Colauzzi, Serra & Amaducci (2018) evaluated biomass sorghum field drying listed stem diameters found in searches of different locations in Italy. It presented an average of 2.04 cm and remained with SD just above the average observed in this study. Hassan et al. (2019), on the other hand, reported 1.13 cm for SD of two forage sorghum cultivars and two dual-purpose cultivars marketed in Pakistan. This result is lower than those presented in this study, which may be explained as these cultivars showed lower DMP and height. Moreover, the author reported that the stem diameter has a positive correlation for these variables. It is believed that in the present study, the stem diameter did not significantly interfere with FMP, similarly to the study by May, Souza, Gravina & Fernandes (2016).

In relation to the leaf number (LN), there was a variation from 7.00 to 12.00 with an average of 10.24 leaves for cultivars. Three distinct groups ($P < 0.050$) were formed and cultivars 23 and 24 had the lowest values for this variable, at 7.00 and 7.33, respectively. For leaf length (LL), there was a variation from 52.75 to 88.42 cm and the formation of two distinct groups ($P < 0.050$), a superior group with values varying 71.17 to 88.42 cm, and a lower group, with values varying from 52.75 to 70.21 cm. The values obtained for the panicle

length (PL) resulted in the formation of three different groups, where significant difference ($P < 0.050$) was observed, ranging from 15.33 to 40.50 cm, and the cultivars presented a general average of 70.72 cm.

Except for cultivars 23 and 24, the observed values were higher than 8 LN for all cultivars observed, remaining above the values found in other studies with sorghum cultivars (Perazzo et al., 2013; Castro et al., 2015). Hassan et al. (2019) in a study already mentioned, found an average similar to the present study with 10.4 LN.

It is worth mentioning that the panicle length did not show any correlation ($r = 0.069$) with the panicle's percentage (Perazzo et al. 2014), shown in Table 3, thus not affect the plant component percentages. Unlike length, weighing this material would likely have a direct influence on the proportion of components, although forage sorghum does not have a well-developed panicle. In a study carried out by Gaddameedi et al. (2018), forage sorghum cultivars were crossed, the average obtained for the panicle length was 22.71 cm.

Regarding the assessment of rain use efficiency (RUE) and water accumulation (WAC) (in kg ha$^{-1}$), the cultivars were also distributed in two distinct groups ($P < 0.050$), with an average of 24.74 kg MS ha$^{-1}$ mm$^{-1}$ and 41.151 kg ha$^{-1}$ respectively. However, the WAC in kg ha$^{-1}$ mm$^{-1}$ showed no differences ($P > 0.050$) among the cultivars (Table 5), varying between 39.17 to 90.41 kg ha$^{-1}$ mm$^{-1}$, with an average of 68.52 kg ha$^{-1}$ mm$^{-1}$.

**Table 5** - Mean values for rain use efficiency (RUE) and accumulation of water (WAC) of thirty-two sorghum cultivars in a semiarid region.

| Cultivars | RUE (kg MS ha$^{-1}$ mm$^{-1}$) | WAC (kg ha$^{-1}$) | WAC (kg ha$^{-1}$ mm$^{-1}$) |
|---|---|---|---|
| Cultivar 1 | 15.81b | 41.616a | 68.22a |
| Cultivar 2 | 19.33b | 48.507a | 79.52a |
| Cultivar 3 | 36.00a | 46.856a | 76.81a |
| Cultivar 4 | 20.73b | 37.520b | 64.82a |
| Cultivar 5 | 27.28a | 42.075a | 68.98a |
| Cultivar 6 | 37.61a | 49.413a | 81.00a |
| Cultivar 7 | 28.65a | 55.150a | 90.41a |
| Cultivar 8 | 28.09a | 43.772a | 71.76a |
| Cultivar 9 | 29.10a | 43.792a | 71.79a |
| Cultivar 10 | 18.18b | 23.895b | 39.17a |
| Cultivar 11 | 25.37a | 40.500a | 66.39a |
| Cultivar 12 | 28.24a | 40.220a | 65.93a |
| Cultivar 13 | 28.12a | 54.771a | 89.79a |
| Cultivar 14 | 23.81a | 43.637a | 75.39a |
| Cultivar 15 | 27.10a | 46.481a | 76.20a |
| Cultivar 16 | 31.01a | 54.831a | 89.89a |
| Cultivar 17 | 29.69a | 44.873a | 73.56a |
| Cultivar 18 | 24.37a | 34.047b | 58.82a |
| Cultivar 19 | 26.26a | 32.148b | 52.70a |
| Cultivar 20 | 21.01b | 41.259a | 67.64a |
| Cultivar 21 | 28.42a | 44.941a | 73.67a |
| Cultivar 22 | 31.08a | 40.630a | 66.61a |
| Cultivar 23 | 18.77b | 31.304b | 54.08a |
| Cultivar 24 | 18.84b | 32.717b | 56.52a |
| Cultivar 25 | 24.55a | 53.139a | 87.11a |
| Cultivar 26 | 28.04a | 45.088a | 77.90a |
| Cultivar 27 | 18.86b | 37.991b | 65.64a |
| Cultivar 28 | 20.74b | 33.719b | 58.25a |
| Cultivar 29 | 19.92b | 28.089b | 54.13a |
| Cultivar 30 | 15.51b | 31.334b | 48.53a |
| Cultivar 31 | 25.99a | 44.277a | 72.58a |
| Cultivar 32 | 15.25b | 28.261b | 48.83a |
| S.E.M | 3.83 | 5.841.92 | 9.67 |
| General Average | 24.74 | 41 151 | 68.52 |

Means followed by different letters in the column differ by the Scott Knott test ($P < 0.05$). S.E.M., standard error of mean. Source: Authors

For the RUE and WAC in kg/ha, the variables showed similarity in the group's formation (cultivars that exhibited higher RUE also obtained greater WAC) because these variables presented a high positive correlation. These results suggest that some cultivars stood out with xerophilic potential and water use, important characteristics for forage cultivated in semi-arid regions.

The RUE appears in the representation of the DMP in relation to rainfall observed during cultivation (578 or 609.08 mm). Therefore, the cultivars produced an average of 24.74 kg DM for each millimeter of rain occurring in one hectare of cultivated sorghum. Elias et al. (2016) with sorghum cultivars under no-tillage obtained higher values (58.51 kg ha$^{-1}$ mm$^{-1}$) although they observed DMP (4.290 kg ha$^{-1}$) and rainfall (73.4 mm) much lower than this study. The cultivars demonstrated that with the end of the rainy seasonality and the occurrence of light rains, the crop showed considerable RUE. Findings with higher mean values (range from 27.3 to 56.5 kg ha$^{-1}$ mm$^{-1}$) have also been reported in the state of Texas, United States, for water use efficiency in different types of irrigation (Hao, Xue, Bean, Rooney & Becker, 2014), and the state of Oklahoma in rainfed conditions, who observed a variation from 9 to 49 kg ha$^{-1}$ mm$^{-1}$ (Yimam, Ochsner & Kakani, 2015).

Water accumulation in some studies mostly is presented in the form of kg ha$^{-1}$ mm$^{-1}$ because it considers the potential of the culture to fresh matter produce based on the adopted precipitation and, or irrigation. However, it may not be observed when evaluating only the accumulation obtained without considering the precipitation. Sousa et al. (2017) carried out a study with drip irrigation with forage sorghum, and they noticed that when the water supplies increased, plants decreased the WAC, having presented the highest value of 97.86 kg ha$^{-1}$ mm$^{-1}$ (273.71 mm) and the lowest 39.00 kg ha$^{-1}$ mm$^{-1}$ (821.15 mm). In irrigation with 410.57 mm, the average observed was practically 70 kg/ha/mm, being the closest to the average observed in the present study.

Furthermore, in relation to the total rainfall, FMP, and the average DMP of some comparative research of sorghum cultivars and hybrids, it may easily observe the average WUE found in the experiment. Therefore, Silva et al. (2011) presented a slightly higher average WUE, with 29.56 kg ha$^{-1}$ mm$^{-1}$ for 25 sorghum silage hybrids. However, when we observed the WAC, the hybrids showed an average of 46.93 kg ha$^{-1}$ mm$^{-1}$. This proves that the evaluated hybrids showed higher using water potential for converting nutrients than in the studied cultivars, but with less water fixation in the tissues, resulting in lower FMP. In the research by Perazzo et al. (2017) also with hybrids for silage, it was possible to observed an average of 16.46 kg ha$^{-1}$ mm$^{-1}$ for RUE and 38.88 kg ha$^{-1}$ mm$^{-1}$ for WAC, both values are below those found in this study, although similar rainfall (635 mm) was observed, showing that these hybrids probably have less xerophilic potential than our cultivars.

Narayanan, Aiken, Vara Prasad, Xin & Yu (2013) demonstrated in their research that evaluating water use efficiency through biomass production is a relevant approach in the selection of sorghum cultivars with high WUE levels under rainfed conditions. It is because

biomass sorghum plants accumulate this high production with the same amount of water available in the soil for the plants during the growing season, thus improving productivity in conditions of low rainfall distribution.

In a comparative study, Roby, Fernandez, Heaton, Miguez & VanLoocke (2017) have emphasized that forage sorghum/biomass presents RUE similar to corn under normal growing conditions. However, in situations of water stress and temperature (summer period) commonly, in semi-arid regions, the response potential of sorghum is higher presenting better results for WUE. The culture characteristic to absorb higher water concentrations due to the thin and branched roots that develop in the subsurface environment and, generally, go into dormancy during the summer and returning to vegetative growth at the time of water availability, evidence its xerophilic power compared to corn.

Due to the semi-arid regions presenting as the scarcest nutrient to the water availability, it is important to show the potential of adapted cultivars with high WUE and WAC, combined with good productivity and nutritional quality of the material to be ensiled. These objectives will lead to an increase in fodder supply for herds in semi-arid regions, mainly when the production of other forage destined for silage is presented as zero or very low due to abiotic factors.

## 4. Final considerations

In this study, sorghum cultivars exhibited high productivity and xerophilic potential. They showed the adaptation capacity to edaphoclimatic conditions for semi-arid regions, mainly because they have high water accumulation based on the observed precipitation.

The formation of groups indicates that it is possible to select those most productive in the edaphoclimatic conditions in which they were evaluated. Experimental cultivars showed greater results than those commercials.

Studies that evaluate the animal performance of cultivars (3, 6, 9, 17, 19, and 31) could be conducted, where obtaining and publishing the results of ingestion, digestibility, daily weight gain or milk production would be complementary to prove their nutritional values since these cultivars stood out for presenting interesting productive characteristics.

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