DOI: 10.5433/1679-0359.2022v43n2p775

Forage sorghum production under rainfed farming in sites with and without climate restriction for maize cultivation

Produção de sorgo forrageiro cultivado em condições de sequeiro com e sem restrição climática para o cultivo de milho

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Highlights

New hybrids with greater adaptability to hot and dry climates.
Forage sorghum production was favorable with BSh climate.
The sorghum hybrid 870031 presented the highest culm production.

Abstract

Forage sorghum is a crop that can be planted in semiarid regions, due to its greater adaptability to dry climate environments, and can replace maize in these regions, which are often unsuitable for its production. Thus, the objective of the study was to evaluate the structural, morphological and nutritional characteristics of 23 sorghum hybrids forage cultivated in rainfed conditions, planted in different climate conditions, comparing the hybrids, in order to determine what produces the best in the climatic conditions of the explored region, and also to indicate whether this crop can be planted as a replacement for maize in environments not suitable for planting it. The research was conducted in climate BSh in the Municipality of Alvorada do Gurgueia, and climate Aw in the Municipality of Bom Jesus, both in the state of Piauí from 2014 to 2015. Each trial consisted of 20 experimental forage sorghum hybrids [*Sorghum bicolor* (L.)

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Received: Aug. 22, 2021 - Approved: Dec. 07, 2021

Moench], and three commercial hybrids. A randomized block design was used, with three replications in a factorial scheme (2 × 23). The growth characteristics determined were hybrid × climate interaction for the variables plant height, lodging and leaf/stem ratio. For the variable number of tillers, there was a significant difference only between hybrids. There was no difference between hybrids only for the lodging variable of climate Aw. The other variables showed a difference in all hybrids evaluated. There was an interaction for production of dead matter and total dry forage mass between the different environments and hybrids evaluated. For leaf production, there was an effect only for the different environments. For the chemical characteristics, there was an interaction for all variables analyzed between the different environments and hybrids evaluated. The semi-arid region of the State of Piauí, climate BSh which presents a high climatic risk for maize cultivation, proved to be favorable for forage sorghum production. The forage sorghum also presented agronomic characteristics similar to those found in semi humid climate Aw, a favorable region for maize cultivation. In addition, the tested hybrids showed good chemical characteristics, so the BSh climate has great exploratory potential for the cultivation of forage sorghum.
Key words: Adaptation. Culm. Dry matter. *Sorghum bicolor.* Roughage.

Resumo

O sorgo forrageiro é uma cultura que pode ser plantada em regiões semiáridas, devido a sua maior adaptabilidade a ambientes de climas secos, podendo substituir a cultura do milho nessas regiões que são impróprias para sua produção. Com isso, o objetivo do trabalho foi avaliar as características estruturais, morfológicas e nutricionais de 23 híbridos de sorgo forrageiro cultivados em regime de sequeiro, plantados em diferentes climas, comparando os híbridos com finalidade de determinar o que melhor produz nas condições climáticas da região explorada, e também para indicar se essa cultura pode ser plantada em substituição ao milho em ambientes não adequados para o plantio do mesmo. A pesquisa foi realizada em clima BSh no município Alvorada do Gurguéia, e clima Aw no município de Bom Jesus, ambos no estado do Piauí nos anos de 2014 a 2015. Cada ensaio consistiu de 20 híbridos experimentais de sorgo forrageiro [*Sorghum bicolor* (L.) Moench] e três híbridos comerciais. O delineamento foi em blocos casualizados com três repetições, em esquema fatorial (2 × 23). Para as características de crescimento, houve interação híbrido × clima para as variáveis altura de planta, acamamento e relação folha/colmo. Para a variável número de perfilhos, houve diferença significativa apenas entre os híbridos. Não houve diferença entre os híbridos apenas para a variável acamamento clima Aw. As demais variáveis apresentaram diferença em todos os híbridos avaliados. Houve interação para produção de matéria morta e massa seca total de forragem entre os diferentes ambientes e híbridos avaliados. Para a produção de folhas, houve efeito apenas para os diferentes ambientes. Para as características químicas, houve interação para todas as variáveis analisadas entre os diferentes ambientes e híbridos avaliados. A região semiárida do Estado do Piauí, clima BSh que apresenta alto risco climático para o cultivo do milho, mostrou-se favorável à produção de sorgo forrageiro. O sorgo forrageiro também apresentou características agronômicas semelhantes às encontradas no clima semiúmido Aw, região favorável ao cultivo do milho. Além disso, os híbridos testados apresentaram boas características químicas, portanto o clima BSh possui grande potencial exploratório para o cultivo de sorgo forrageiro.
Palavras-chave: Adaptação. Colmo. Matéria seca. *Sorghum bicolor.* Volumoso.

Introduction

In order to increase the food security of herds in semiarid regions, studies with forage species resistant to water stress are important. In this context, the cultivation of forage sorghum [*Sorghum bicolor* (L.) Moench] would be one of the alternatives, mainly to replace maize (*Zea mays* L.) widely cultivated in many parts of the world. However, in some regions of the planet, due to the water issue and irregular rainfall, it is not recommended to plant maize in a rainfed regime, as there is great risk of losses (Major, McGinn, & Beauchemin, 2021). In this sense, in a climatic risk zoning for maize crop in the State of Piaui, A. S. Andrade, Bastos, Cardoso and Silva (2008) observed that in the semi-arid region of the state, there was always a high climatic risk for the maize crop. Thus, the replacement of maize by forage sorghum in these regions reduces the seasonality of forage production, allowing the production of enough forage to feed the animals throughout the year, as well as increasing the pressure for grazing due to the higher availability of food.

After maize, forage sorghum is the second most used grass in animal feed in the form of silage, as it presents higher production per harvested area and similar nutritional values in the vast majority of genotypes and hybrids currently sold, with about 70 g kg^{-1} crude protein (CP), 650 g kg^{-1} neutral detergent fiber (NDF), and 400 g kg^{-1} acid detergent fiber (ADF) on a dry matter (DM) basis (Angadi et al., 2016).

Originating in Africa, sorghum is adapted to grow in arid and semi-arid environments (Hmielowski, 2017; Manarelli et al., 2019). As it is a plant with C4 metabolism, it has high photosynthetic capacity with great inherent potential for biomass production. Its tolerance to water deficit (Behling et al., 2017), and high temperature, in addition to adapting to the low fertility inherent in the soil, make farming it progressively more relevant to food security in the face of climate change (Abdelhalim, Kamal, & Hassan, 2019); it has high productivity in crop systems compared to maize.

In addition, sorghum can be planted in succession to other crops, which can allow a second harvest in a single growing season, with a high regrowth capacity, around 30% to 70% of what was harvested in the first cut (Pino & Heinrichs, 2017). It adapts well to mechanization, is versatile (hay, silage and direct pasture) (Costa et al., 2016).

In order to improve nutritional quality and increase the production and climatic resistance of forage sorghum, new hybrids have been developed, with high CP content, reduced lignification, and increased digestibility and fiber utilization, in addition to higher adaptability to hot and dry climates (Kljak, Pino, & Heinrichs, 2017). Therefore, the choice of appropriate genotype is essential to establish an efficient production system (Pinho et al., 2015), which reduces losses due to climatic variations.

Combined with the choice of the best variety, environmental factors beyond human control have an important role in the behavior of the crop. They are definitive both at the time of planting and in terms of the productivity and chemical composition, as they have a very large influence on the physiology of the plant (Akinseye et al., 2020). According to Wolabu and Tadege (2016), this is mainly because sorghum is a plant for short days, and the variation in response to the photoperiod and temperature determines its suitability for the wide range of different environments in which it is grown. Therefore, most development takes place over a period of decreasing light duration, which explains why its cycle shortens when sowing is postponed during the rainy season (Sanon et al., 2014).

Therefore, research on the agronomic and nutritional characterization of these sorghum hybrids is essential for providing a more precise recommendation for the most diverse uses in production systems, especially in regions where the cultivation of maize is not recommended. Thus, this work was developed with the objective of agronomically and chemically characterizing 23 forage sorghum hybrids grown under rainfed conditions, planted under two climates, comparing the hybrids and pointing out the one that best produces in the climatic conditions of the explored region, and further indicating whether this crop can be planted to replace maize in regions not suitable for planting.

Material and Methods

Location

The experiment was conducted in two different climates, according Alvares, Stape, Sentelhas, Gonçalves and Sparovek (2013). Hot semi-arid climate BSh, with a dry summer and winter rains and average rainfall of between 400 and 600 mm year^{-1}, is located in the municipality of Alvorada do Gurgueia, Piauí, Brazil (08°25'28" S and 43°46'38" W, altitude 281 m). Data regarding rainfall, relative air humidity, and maximum and minimum temperature during the cultivation period of forage sorghum hybrids, which took place from November 15, 2014 to April 17, 2015, are shown in (Figure 1).

Climate Aw with winter dry season, with average rainfall between 600 and 800 mm year^{-1}, it is located in Bom Jesus, Piauí, Brazil (09°04'28" S and 44°21'31" W, altitude 277 m) and presents a maximum temperature of 36 °C and minimum of 18 °C (Alvares et al., 2013). The data regarding precipitation, relative air humidity and maximum and minimum temperature during the cultivation period of forage sorghum hybrids, which occurred from November 10, 2014 to April 9, 2015, are presented in (Figure 2).

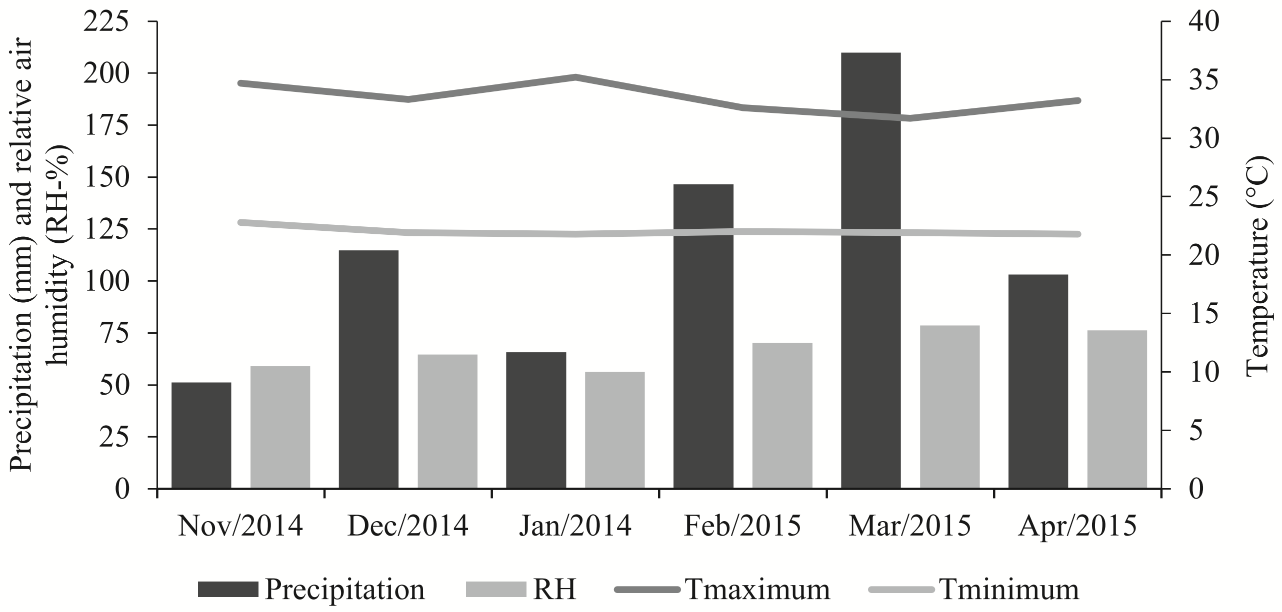

Figure 1. Meteorological data for climate BSh during the cultivation of forage sorghum hybrids from November 15, 2014 to April 17, 2015.
Source: http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep. Station: 82870 - Vale do Gurgueia Cristino Castro, PI. Tmaximum: Maximum temperature. Tminimum: Minimum temperature.

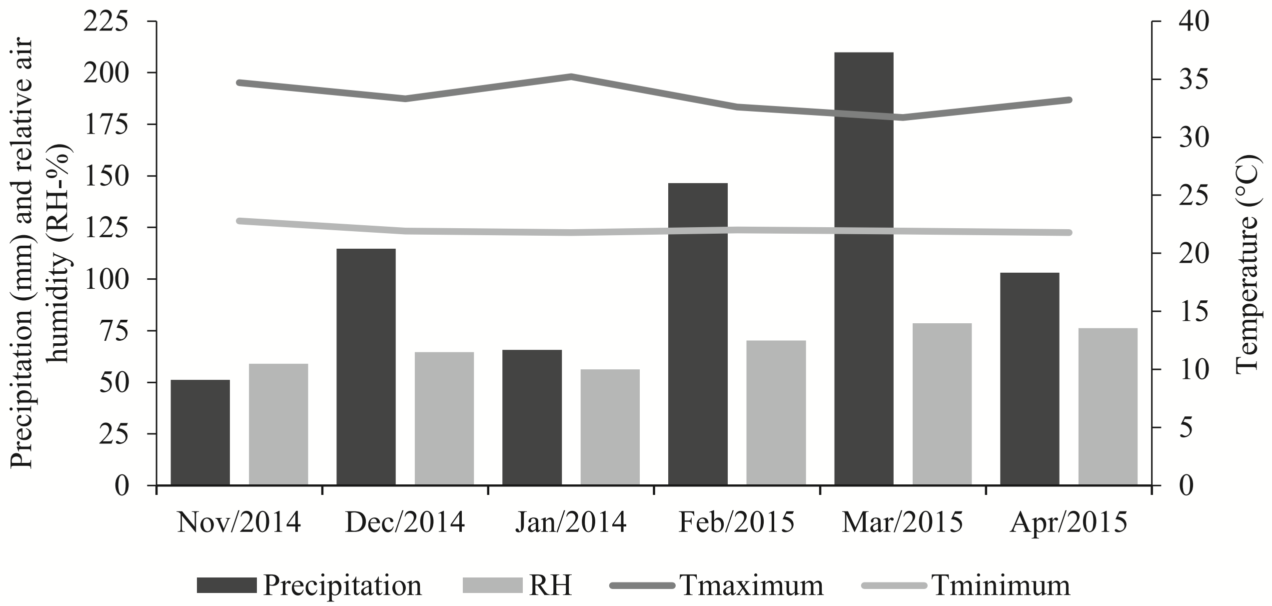

Figure 2. Meteorological data for climate Aw during the cultivation of forage sorghum hybrids from November 2014 to April 2015.
Source: http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep. Station: 82975 - Bom Jesus, PI. Tmaximum: Maximum temperature. Tminimum: Minimum temperature.

Tested hybrids and experimental design

Each trial consisted of 20 experimental forage sorghum hybrids [Sorghum bicolor (L.) Moench] designated by codes (866005, 866019, 866033, 866034, 866035, 866037, 866040, 866041, 866042, 866043, 866044, 870025, 870031, 870035, 870041, 870051, 870067, 870081, 870085 and 870095) and three commercial hybrids (BRS 610, XBS60329 and 1F305), both developed and supplied by Embrapa Milho e Sorgo, located in the municipality of Sete Lagoas, MG.

The experiment was established following a randomized block design (RBD), with three replications in a 2 × 23 factorial scheme, with two types of climates and 23 sorghum hybrids, which hybrids were blocked in accordance with the slope of the soil.

Experimental area, fertilization and planting

In each trial, an area of 620 m^2 was used, divided into 75 plots of 4 m2 each (2 m × 2 m), totaling an area of 1240 m2 and 150 plots in both trials, with 0.50 m line spacing totaling five rows per plot and 2 m between non-cultivated blocks. Before implementing the experiment, soil samples were collected from both locations for analysis and chemical characterization in the 0-20 cm layer of soil. The soil of the experimental area of climate BSh was classified as Dystrophic Red-Yellow Latosol soil associated with Quartz Sand and of the experimental area of climate Aw was classified as Ribic Dystric Arenosol, according from reference by Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA] (2018).

According to the analyses, in the experimental area of climate BSh, 40 kg of phosphorus (P) ha^{-1} was applied in the form of simple superphosphate (18% P_2O_5) and 60 kg of potassium (K) ha^{-1} in the form of potassium chloride (48% K_2O); 40 days after planting, 70 kg of nitrogen (N) ha^{-1} was applied in the form of urea (45% N). In the soil of the experimental area of climate Aw, the basic fertilization consisted of the application of 50 kg ha^{-1} of N in the form of urea, 50 kg ha^{-1} of K in the form of potassium chloride and 30 kg ha^{-1} of P in the form of simple superphosphate according to recommendations of Sousa and Lobato (2004).

According Medina-Méndez, Soto-Rocha, Hernández-Pérez and Gómez-Tejero (2021), planting was done at the beginning of the rainy season on November 10, 2014; 14 seeds per linear meter were distributed in furrows approximately 3 cm in depth, aiming at a final population of 140,000 plants ha^{-1},

Procedures for evaluating agronomic characteristics

Evaluations and harvesting of the sorghum hybrids were carried out at the same phenological stage, when the grains were farinaceous (Tables 1 and 2). At this stage, the cut was made at a height of 10 cm from the ground; plants from the useful area of each plot (2 m central linear) were used for the evaluations, the lateral lines considered as edges being discarded.

Table 1
Cultivation period of forage sorghum hybrids in climate environment BSh

Sorghum hybrids	Planting	Cutting	Age (days)
866034, 866035, 866043, 866044, 870025, 870081	15/11/2014	24/02/2015	101
866033, 866037, 866040, 1F305	15/11/2014	14/03/2015	119
866005, 866019, 866041, 866042, 870031, 870035, 870041, 870051, 870067, 870085, 870095, BRS 610, XBS60329	15/11/2014	17/04/2015	153

Total plant height, number of tillers per linear meter (LM), lodging and leaf/stem ratios (L/S) were evaluated. Leaf mass, stem mass, panicle mass, senescent material (SM) green forage mass (GFM) and dry forage mass (DFM) were determined (t ha^{-1}). The number of tillers/LM was obtained by averaging the number of total plants and tillers in the useful area. Height was considered as the average height of five plants chosen at random and measured with a tape measure. The plants present within the useful area were cut and weighed on a precision scale to obtain the green mass.

Table 2
Cultivation period of forage sorghum hybrids in climate environment Aw

Sorghum hybrids	Planting	Cutting	Age (days)
866005, 866019, 866034, 866035	10/11/2014	11/03/2015	121
866037, 866040	10/11/2014	26/03/2015	136
866033, 866041, 866042, 866043, 866044, 870025, 870031, 870035, 870041, 870051, 870067, 870081, 870085, 870095, 1F305, BRS 610, XBS60329	10/11/2014	09/04/2015	150

For morphological characteristics, two plants from the useful area were selected, from which leaves, stems, SM and panicles were separated and weighed individually to obtain the fresh matter (FM) weight. The samples were put in a forced ventilation oven at 55 °C for 72 h, thus obtaining the dry mass, according to Association of Official Analytical Chemists [AOAC] (2012), then the morphological characteristics of productivity (t ha^{-1}) were quantified.

Evaluation of chemical composition

The plants were processed in a stationary forage harvester, obtaining pieces approximately 2 cm in size, from which an approximately 400 g sample was removed and packed in paper bags for pre-drying according to the methodology described by AOAC (2012). Then, the samples were subjected to grinding in a Wiley mill using a 1 mm sieve, and packed in containers with lids.

AOAC (2012) methods were used to determine the levels of DM, ash and CP in nitrogen distillation apparatus, using the Kjeldahl method. The organic matter (OM) content was obtained by difference to the values found for ash.

For NDF and ADF, the method of Van Soest, Robertson and Lewis (1991), was adopted, using non-woven fabric bags as recommended by Detmann, Souza and Valadares (2012), and an autoclave according to Senger et al. (2008). For NDF analysis, three drops (50 μL) of α-amylase were added to each sample in the detergent and water solution, following the recommendations proposed by Van Soest et al. (1991). Lignin (LIG) were evaluated using the sequential method also proposed by Van Soest et al. (1991).

Statistical analysis

The data were submitted to analysis of variance and analyzed by the Scott-Knott test at the significance level of 0.05, using SISVAR software version 5.0 (Ferreira, 2011). The statistical model adopted was:

$$Yik = \mu + Hi + Bk + \epsilon ik$$

where:

Yik = observation of sorghum hybrid i in repetition *k*;

μ = overall average;

Hi = effect of hybrid *i*, with *i* = 1, 2, 3 ... 23;

Bj = effect of block *k*, where *k* = 1, 2 and 3;

ϵ*ik* = experimental error associated with the observed values (*Yik*).

Results and Discussion

Growth characteristics

For growth characteristics (Table 3), there was an interaction (p <0.05) for plant height, lodging and L/S ratio between the different climates and sorghum hybrids. For the variable number of tillers, there was a difference (p <0.05) only between sorghum hybrids. There was no difference between the sorghum hybrids (p = 0.05) only for the lodging variable of Aw climate.

Table 3
Growth characteristics among forage sorghum hybrids

Sorghum hybrids	Height Plant (cm) ---Climate---		Tillers (LM)[1]	Lodging (%) ---Climate---		L/S[2] ---Climate---	
	BSh	Aw		BSh	Aw	BSh	Aw
866005	180.7Ca	154.7Ab	11.7A	9.0 Ca	0.0Aa	0.2Ca	0.2Aa
866019	186.7Ca	173.7Aa	11.7A	24.5Ba	0.0Ab	0.2Ca	0.1Ba
866033	176.5Ca	160.3Aa	11.4A	20.8Ba	0.0Ab	0.3Ba	0.2Ab
866034	205.0Ba	167.0Ab	9.5B	8.9Ca	0.0Aa	0.2Ca	0.2Ba
866035	200.0Ba	141.2Ab	8.2C	5.9Ca	3.0Aa	0.2Ca	0.2Aa
866037	169.9Da	165.3Aa	7.0C	3.0Ca	14.3Aa	0.3Ca	0.2Aa
866040	150.7Da	143.9Aa	7.5C	0.0Ca	0.0Aa	0.3Ba	0.2Aa
866041	213.3Ba	171.9Ab	7.6C	20.3Ba	2.4Ab	0.2Ca	0.2Ba
866042	185.7Ca	157.5Ab	8.1C	4.2Ca	3.9Aa	0.4Aa	0.2Ab
866043	206.2Ba	163.3Ab	8.6C	22.9Ba	3.3Ab	0.3Ba	0.2Aa
866044	198.7Ba	153.2Ab	6.5C	35.3Aa	0.0Ab	0.2Ca	0.2Aa
870025	179.1Ca	158.5Aa	6.3C	0.0Ca	0.0Aa	0.2Ca	0.2Aa
870031	239.1Aa	168.8Ab	6.2C	11.9Ca	0.0Aa	0.2Ca	0.1Ba
870035	181.9Ca	155.7Ab	7.0C	40.9Aa	1.7Ab	0.4Aa	0.1Bb
870041	189.0Ca	170.2Aa	9.1B	50.0Aa	9.8Ab	0.1Ca	0.2Ba
870051	186.6Ca	172.5Aa	8.7B	22.5Ba	0.0Ab	0.2Ca	0.1Ba
870067	202.5Ba	161.4Ab	6.8C	17.4Ca	0.0Ab	0.4Aa	0.2Ab
870081	167.4Da	160.8Aa	6.8C	2.8Ca	0.0Aa	0.4Aa	0.2Ab
870085	223.4Aa	164.5Ab	7.0C	4.4Ca	0.0Aa	0.3Ba	0.1Bb
870095	186.4Ca	157.3Ab	7.9C	4.2Ca	7.4Aa	0.2Ca	0.1Ba
1F305	174.9Ca	179.7Aa	8.5C	5.9Ca	4.2Aa	0.2Ca	0.2Ba
BRS 610	203.0Ba	138.9Ab	9.2B	7.7Ca	0.0Aa	0.2Ca	0.2Ba
XBS60329	154.3Da	106.9Bb	9.7B	8.0Ca	2.4Aa	0.4Aa	0.1Bb
p-value							
Hybrids	<0.001		<0.001	<0.001		<0.001	
Climate	<0.001		0.048	<0.001		<0.001	
Hybrids × Climate	<0.001		0.021	<0.001		<0.001	
SEM[3]	8.7		7.8	4.9		0.03	

[1]LM: linear meter; [2]L/S; leaf/stem ratio; [3]SEM: standard error of the mean. Uppercase letters in the columns compare hybrids within the cluster and lowercase letters in the rows compare climates. Means followed by the same capital letters in the same column do not differ by the Scott-Knott procedure, at the level of 5% probability, and the same lowercase letters in the same row do not differ by the Scott-Knott procedure, at the level of 5% probability.

In relation to the height of the plants, sorghum hybrids 870031 and 870085 were grouped with higher average ($p < 0.05$) in the two climates, with the same averages of 223.4 and 239.1 cm in BSh climate. Sorghum hybrids 866034, 866035, 866041, 866043, 866044, 870067 and BRS 610 formed a second group with mean ranging from 198.7 to 213.3 cm. Sorghum hybrids 866005, 866019, 866033, 866042, 870025, 870035, 870041, 870051, 870095 and 1F305 formed the third group with averages ranging from 176.5 to 189 cm. Sorghum hybrids 866037, 866040, 870081 and XBS60329 were grouped with a height less than 176.5 cm. In Aw climate, twenty-two sorghum hybrids group presenting higher average plant height, ranging from 141.2 to 179.7 cm. The XBS60329 hybrid showed a mean height of 106.9 cm.

Plant height is an important agronomic component that affects biomass production (Williams-Alanís, Zavala-García, Arcos-Cavazos, Rodríguez-Vázquez, & Olivares-Sáenz, 2017), and both hybrids that had higher average heights in both locations were influenced by the climate of the region. In Aw climate, although the rainfall regime was higher than in BSh climate with a rainfall of 1012,5 mm throughout the production cycle, there were lower thermal indices, which may have contributed to the shorter stature of plants in comparison with climate BSh, which had higher temperature averages. The results in both locations were similar to those observed by Lima et al. (2017) studying variation in the height of sorghum hybrids plants in four municipalities in the Brazilian states of Goiás, Rio Grande do Sul and Minas Gerais, with averages ranging from 180 to 283 cm.

The number of tillers/LM of sorghum hybrids ranged from 6.2 to 11.7, with a higher ($p < 0.05$) average to hybrids 866005, 866019 and 866033 averages ranging from 11.4 to 11.7 tillers/LM. Sorghum hybrids 866034, 870041, 870051, BRS 610 and XBS60329 were grouped in an intermediary group with averages ranging from 8.7 to 9.7 tillers/LM. And sorghum hybrids 866035, 866037, 866040, 866041, 866042, 866043, 866044, 870025, 870031, 870035, 870067, 870081, 870085, 870095 and 1F305 presented the lower averages, ranging from 6.2 to 8.6 tillers/LM. The number of tillers/LM did not differ significantly ($p > 0.05$) between the two climates.

The difference in the number of tillers among the hybrids can be explained due to their different morphologies, as also observed in the size of the plants. A higher number of tillers in a forage sorghum hybrid is an important characteristic, as they occupy more space in the area, making it difficult for invasive plants to appear. In addition, it is indicative of the persistence of grasses and their productive capacity after cutting, and a higher tillering contributes to improve productivity and sustainability of pastures, as the forage production of the entire plant community is based on the individual contribution of each tiller multiplied by its density (Gomes, Pitombeira, Neiva, & Cândido, 2006; Tiritan, Santos, Minutti, Foloni, & Calonego, 2013).

In BSh climate, sorghum hybrids 866044, 870035 and 870041 formed a group with higher ($p < 0.05$) lodging, with mean ranging from 35.3 to 50%. Sorghum hybrids 866019, 866033, 866041, 866043 and 870051 formed a group with mean values ranging from 20.3

to 24.5% lodging. The other hybrids, 866005, 866034, 866035, 866037, 866040, 870025, 870031, 870067, 870081, 870085, 870095, 1F305, BRS 610 and XBS60329, formed a group with lower average values ranging from 0 (zero) to 17.4% lodging. In Aw climate, all sorghum hybrids formed a single group with average values ranging from 0 to 14.3% lodging.

The higher degree of lodging in BSh climate may be related to the higher height of the plants present in them. However, other factors can provide higher lodging, such as the presence of large flocks of birds that feed on sorghum grains. This is an undesirable variable in a choice of a forage hybrid, because a higher lodging reduces the forage mass, as these plants are not harvested by machinery at the time of cutting (Rabelo, Rabelo, Dupas, Nogueira, & Rezende, 2012).

In BSh climate, hybrids 866042, 870035, 870067, 870081 and XBS60329 were grouped with higher ($p < 0.05$) average L/S of 0.4. Sorghum hybrids 866033, 866040, 866043 and 870085 formed a group with average L/S of 0.3. The other hybrids formed a group with average L/S below 0.3. In climate Aw, sorghum hybrids 866005, 866033, 866035, 866037, 866040, 866042, 866043, 866044, 870025, 870067 and 870081 were grouped with the highest L/S ratio, on average 0.2. The other sorghum hybrids formed a group with average L/S of 0.1. The higher plant height in BSh climate did not provide a lower L/S ratio as expected, probably due to the fact that the plants had a smaller diameter compared to plants in Aw climate.

There was an interaction ($p < 0.05$) for the production of SM and DFM between the different climates and sorghum hybrids evaluated. For leaf mass, there was an effect ($P < 0.05$) only for different climates. Stem and panicle production showed isolated effects for the climate and sorghum hybrids. For the production of GFM, there was a difference ($p < 0.05$) only between sorghum hybrids (Table 4). For the leaf mass, there was no significant difference between hybrids, with averages ranging from 4.9 to 12.9 t ha^{-1}. The BSh climate had a higher average of 8.2 t ha^{-1}, while in Aw climate the average value was 6.4 t ha^{-1}. The Aw climate presented the largest quantity, probably due to the climatic conditions of the region, as sorghum is sensitive to the photoperiod and its productivity is related to these factors. The Aw climate is classified as with winter dry season, with a higher accumulation of rainfall during the cultivation period of 1012.5 mm, when compared to BSh climate which had an accumulation of 691.1 mm, which may also have favored higher leaf production.

Sorghum hybrid 870031 showed higher stem mass ($p < 0.05$), with an average value of 62.3 t ha^{-1} (Table 4). Sorghum hybrids 866043, 870035, 870041, 870051, 870085 and 870095 formed a group with average values ranging from 40.2 to 44.7 t ha^{-1}. In a 3th group, with sorghum hybrids 866019, 866033, 866034, 866035, 1F305 and BRS 610 presented mean values ranging from 33.4 to 36.7 t ha^{-1}. The other sorghum hybrids (866005, 866037, 866040, 866041, 866042, 866044, 870025, 870067, 870081 and XBS60329) were grouped with the lowest ($p < 0.05$) average stem mass values, varying from 22 to 34 t ha^{-1}. The Aw climate presented a higher average ($p < 0.05$) for stem mass, with a value of 36.9 t ha^{-1}, despite lower average height, while in climate BSh it was 29.8 t ha^{-1}. This can be explained due to the larger diameter of plants in this climate. The stem mass is the least digestible part of the plant, as it has a relatively low CP content and high ADF and NDF content compared to other parts of the plants (Kaplan et al., 2019).

For panicle production, sorghum hybrids 866043, 870031, 870035, 870081 and 870095 were grouped with higher ($p < 0.05$) averages, ranging from 6.6 to 9.0 t ha^{-1}. The other sorghum hybrids were grouped with lower ($p < 0.05$) panicle production averages ranging from 3.3 to 5.8 t ha^{-1}. The Aw climate presented a higher average value of 6.4 t ha^{-1}, while in climate BSh it was 4.2 t ha^{-1}. High amounts of panicles represent a good characteristic for a forage sorghum hybrid, as according to I. V. O. Andrade, Pires, Carvalho, Veloso and Bonomo (2010), the panicle increases the levels of DM and soluble carbohydrates in silage, favoring the fermentation process. It is the more digestible part of the plant, while the stem is less digestible as it is the fraction of the plant with high levels of fiber and LIG. Thus, the increase in the participation of grains has a dilutive effect on the fiber content, even though it increases in the vegetative part of the plant (Moraes, Jobim, Silva, & Marquardt, 2013).

In BSh climate, sorghum hybrids 870035, 870041, 870051, 870085, 870095 and 1F305 were grouped with higher ($p < 0.05$) average SM, ranging from 2.8 to 3.8 t ha^{-1}. There was no significant difference between others hybrids ($p > 0.05$) with averages ranging from 0.7 to 2.1 t ha^{-1}. In BSh climate, there was no significant difference ($p > 0.05$) between hybrids with averages ranging from 0.3 to 2 t ha^{-1}. The 870035 hybrids showed a higher mean SM, withouth significant difference ($p > 0.05$) between climates, with values of 2.0 t ha^{-1} to BSh climate and 2.9 t ha^{-1} to Aw climate. That interaction found in the production of SM between the different climates evaluated can be explained by the acceleration of the cycle between the sorghum hybrids a consequence of the difference in rainfall between the two locations during the cultivation period. The sorghum hybrids that had lower SM production stand out from the others because a larger portion of SM in forage provides a food of worse quality.

Table 4
Characterization of forage mass production among forage sorghum hybrids

Hybrids	GFM[1] (t ha^{-1})	DFM[4] (t ha^{-1}) ---Climate---		Leaf mass in FM[2] (t ha^{-1})	Stem in FM[2] (t ha^{-1})	Panicle in FM[2] (t ha^{-1})	SM[3] in FM[2] (t ha^{-1}) ---Climate---	
		BSh	Aw				BSh	Aw
866005	39.1B	11.6Ba	16.2Ba	4.9A	27.7D	3.7B	1.5Aa	2.0Ba
866019	44.8B	19.3Aa	11.5Ba	5.9A	33.5C	3.7B	1.3Aa	1.5Ba
866033	51.3A	20.0Aa	17.1Ba	8.7A	33.4C	3.6B	1.9Aa	0.7Ba
866034	48.2A	22.4Aa	11.7Bb	6.5A	33.7C	4.9B	1.6Aa	0.8Ba
866035	51.1A	25.8Aa	8.9Bb	8.7A	34.8C	5.5B	0.6Aa	0.8Ba
866037	36.6B	11.0Ba	14.5Ba	5.9A	25.6D	3.3B	0.3Ab	1.9Ba
866040	38.1B	14.3Ba	15.2Ba	6.7A	25.6D	4.6B	0.6Aa	0.7Ba
866041	47.7A	19.6Aa	19.9Ba	6.7A	34.0D	5.1B	1.1Aa	2.0Ba
866042	33.7B	14.1Ba	13.4Ba	5.3A	23.4D	3.5B	0.7Aa	1.4Ba
866043	59.6A	22.2Aa	13.4Ba	9.6A	40.2B	6.8A	1.9Aa	1.0Ba
866044	39.3B	17.3Ba	7.0Bb	6.0A	25.2D	5.8B	1.3Aa	0.7Ba
870025	46.8A	21.2Aa	10.6Bb	7.5A	32.8D	4.7B	0.7Aa	0.8Ba
870031	72.8A	29.5Aa	31.1Aa	9.6A	62.3A	9.0A	1.7Aa	1.7Ba
870035	62.2A	23.9Aa	27.2Aa	9.5A	41.6B	8.4A	2.0Aa	2.9Aa
870041	56.7A	17.7Ba	26.5Aa	6.5A	43.0B	5.0B	1.2Ab	2.8Aa
870051	54.8A	15.6Ba	23.8Aa	6.6A	40.2B	5.5B	1.0Ab	3.5Aa
870067	36.6B	14.2Ba	16.9Ba	5.3A	24.6D	4.2B	1.3Aa	2.0Ba
870081	48.3A	17.5Ba	12.7Ba	8.6A	30.3D	6.6A	1.2Aa	0.8Ba
870085	61.5A	23.3Aa	21.1Aa	9.2A	43.7B	5.4B	1.2Ab	3.4Aa
870095	63.9A	23.6Aa	25.9Aa	8.7A	44.7B	7.6A	1.4Ab	3.4Aa
1F305	51.4A	18.8Aa	24.1Aa	7.4A	36.7C	4.6B	0.6Ab	3.8Aa
BRS 610	49.4A	19.1Aa	20.7Aa	12.9A	34.8C	5.5B	1.9Aa	2.1Ba
XBS60329	35.3B	16.4Ba	11.9Ba	6.4A	22.0D	4.0B	1.3Aa	2.1Ba
Climate								
1	46.5A	-	-	6.4B	29.8B	4.2B	-	-
2	48.9A	-	-	8.2A	36.9A	6.4A	-	-
p-value								
Hybrids	<0.001	<0.001		0.023	<0.001	<0.001	<0.001	
Climate	0.033	0.011		0.001	<0.001	<0.001	<0.001	
Hybrids × Climate	0.048	0.001		0.044	0.031	0.081	<0.001	
SEM[5]	6.3	3.4		1.8	4.2	0.9	0.5	

[1]GFM: green forage mass; [2]FM: fresh matter; [3]SM: senescent material; [4]DFM: dry forage mass;
[5]SEM: standard error of the mean. Uppercase letters in the columns compare hybrids within the cluster and lowercase letters in the rows compare climates. Means followed by the same capital letters in the same column do not differ by the Scott-Knott procedure, at the level of 5% probability, and the same lowercase letters in the same row do not differ by the Scott-Knott procedure, at the level of 5% probability.

For the GFM variable, sorghum hybrids 866033, 866034, 866035, 866041, 866043, 870025, 870031, 870035, 870041, 870051, 870081, 870085, 870095, 1F305 and BRS 610 were grouped with higher GFM average values ($p < 0.05$), ranging from 47.7 to 72.8 t ha^{-1}. These values are related mainly to the higher height, higher proportion of leaves and the inherent productive capacity of these hybrids. The other hybrids, 866005, 866019, 866037, 866040, 866042, 866044, 870067 and XBS60329, were grouped with lower averages, ranging from 33.7 to 44.8 t ha^{-1}. There was no significant difference ($p > 0.05$) between the two climates. The means were higher than those found by Elias et al. (2017), when they evaluated sorghum cultivars in the semi-arid region of Pernambuco state and found averages ranging between 7 and 20 t ha^{-1}.

Sorghum hybrids 866019, 866033, 866034, 866035, 866041, 866043, 870025, 870031, 870035, 870085, 870095, 1F305 and BRS 610 formed a group with the highest average DFM ($p < 0.05$) in climate BSh, ranging from 18.8 to 29.5 t ha^{-1}. Thus, as observed for GFM production, DFM production followed the same trend for most hybrids in BSh climate, presenting higher yields compared to climate Aw. The other sorghum hybrids (866005, 866037, 866040, 866042, 866044, 870041, 870051, 870067, 870081 and XBS60329) were grouped with lower mean values ranging from 11 to 17.7 t ha^{-1}. Sorghum hybrids 870031, 870035, 870041, 870051, 870085, 870095, 1F305 and BRS 610 were grouped with higher averages in Aw climate, ranging from 11 to 31.1 t ha^{-1}. The other sorghum hybrids (866005, 866019, 866033, 866034, 866035, 866037, 866040, 866041, 866042, 866043, 866044, 870025, 870067, 870081 and XBS60329) formed a group with lower ($p < 0.05$) DFM averages, ranging from 7.0 to 19.9 t ha^{-1}. The hybrids that had the highest average DFM without a significant difference ($p > 0.05$) between the two climates were 870031, 870035, 870085, 870095, 1F305 and BRS 610, with averages ranging from 18.8 to 31.1 t ha^{-1}, keeping the highest yields in both climates, showing great adaptability to different climates for this variable.

The production of DFM is related to the management style adopted and the productive capacity of the hybrid and its adaptability to the climatic environment in which it is planted. Evaluating the same sorghum hybrids in the northeastern semi-arid region, Silva et al. (2012) found DFM values higher than those found in the present study, varying between 23.4 and 42.1 t ha^{-1}.

Chemical composition

There was an interaction ($p < 0.05$) for the variables DM, OM, CP, NDF, ADF, and LIG between the different climates and hybrids evaluated, as shown in Table 5. In BSh climate, all hybrids presented similar ($p > 0.05$) DM content, with averages ranging from 328 to 386 g kg^{-1} FM. The highest DM content observed in BSh climate are related to the highest average values of dead matter existing in all hybrids in this location, where the majority presented values within the range recommended for the production of silage, between 300 and 350 g kg^{-1} FM at the time of cutting. Another explanation for this is the lower rainfall in this climate at the time of this cutting because its cycle by increasing DM concentrations.

In Aw climate, sorghum hybrids 866037, 866040, 866041, 866042, 870031, 870035, 870041, 870051, 870067, 870085, 870095, 1F305, BRS 610 and XBS60329 were grouped with the highest ($p < 0.05$) DM average, ranging from 310 to 378 g kg^{-1} FM. The high concentration of DM at the time of cutting, observed in these hybrids impairs the nutritional value of the forage. According to Van Soest (1994), a DM content higher than 350 g kg^{-1} FM can cause damage to the silage, due to the presence of oxygen, caused by inefficient compaction of the material. The other hybrids were grouped with lower DM averages, ranging from 238 to 296 g kg^{-1} FM. These stayed below those recommended for silage production. This is probably due to high rainfall at the time of cutting.

The sorghum hybrids cultivated in Aw climate presented also high DM average similarly ($p > 0.05$) BSh climate, varying from 310 to 386 g kg-1 FM. The values obtained in the present study were similar to those found by Perazzo et al. (2017), which observed DM content average ranging from 220 g to 400 g kg^{-1} FM from 21 experimental sorghum hybrids cultivation.

For OM content, sorghum hybrid 866033 had the lowest OM average in BSh climate (832 g kg^{-1} DM). The others were grouped with similar OM content average, ranging from 917 to 967 g kg^{-1} DM. In Aw climate, there was no difference ($p > 0.05$) between sorghum hybrids to OM, with average ranging from 925 to 958 g kg^{-1} DM. The sorghum hybrids with the highest ($p < 0.05$) OM mean in the two climates were 866005, 866019, 866037, 866040, 866042, 866043, 866044, 870025, 870031, 870051, 870081, 870085, 870095, 1F305 and BRS 610, with averages ranging between 917 and 965 g kg^{-1} DM in both climates.

The levels of OM observed in both climates were similar to those found by Paraíso et al. (2017), which reported 940 to 960 g kg^{-1} DM in six sorghum hybrids. When evaluating three varieties of forage sorghum irrigated with saline effluents from fish farming, Simões, Guimarães, Araújo, Perazzo and Prates (2019), found an OM content of 945 g kg^{-1} DM for hybrid 1F305, similar to those found in the present study in both climates.

In Aw climate, sorghum hybrids 866005, 866019, 866033, 866034, 866037, 866040, 870025 and 870081 were grouped with the highest ($p < 0.05$) CP content averages, ranging from 101 to 117 g kg^{-1} DM. The higher participation of leaves and panicles observed in Aw climate, contributed to the highest concentrations of CP observed, with satisfactory averages for all sorghum hybrids, because a feed and/or diet must contain at least 70 g kg^{-1} DM of CP to provide enough nitrogen for effective microbial fermentation in the rumen (Van Soest, 1994). Sorghum hybrids 866035, 866041, 866042, 866043, 866044, 870031, 870035, 870041, 870051, 870067, 870085, 870095, 1F305, BRS 610 and XBS60329 were grouped with the lowest CP averages, ranging from 75 to 95 g kg^{-1} DM. The CP content of hybrids 866005, 866019, 866033, 866034, 866037, 866040 and 870025 did not differing statistically ($p > 0.05$) between the two climates ranging from 84 to 114 g kg^{-1} DM.

Table 5
Chemical composition among forage sorghum hybrids in climates of different classification

Sorghum hybrids	DM[1] g kg^{-1} FM ---Climate---		OM[2] g kg^{-1} DM ---Climate---		CP[3] g kg^{-1} DM ---Climate---		NDF[4] g kg^{-1} DM ---Climate---		ADF[5] g kg^{-1} DM ---Climate---		LIG[6] g kg^{-1} DM ---Climate---	
	BSh	Aw	BSh	Aw	BSh	Aw	BSh	Aw	BSh	Aw	BSh	Aw
866005	328.0Aa	289.0Ba	961.0Aa	938.0Aa	86.0Aa	110.0Aa	684.0Aa	757.0Aa	324.0Aa	312.0Aa	60.0Aa	38.0Bb
866019	376.0Aa	239.0Bb	917.0Aa	933.0Aa	84.0Aa	102.0Aa	687.0Ab	754.0Aa	353.0Aa	339.0Aa	66.0Aa	59.0Aa
866033	371.0Aa	296.0Bb	832.0Bb	934.0Aa	105.0Aa	107.0Aa	618.0Ba	783.0Aa	339.0Aa	355.0Aa	43.0Bb	63.0Aa
866034	374.0Aa	261.0Bb	952.0Aa	925.0Ab	91.0Aa	114.0Aa	678.0Ab	763.0Aa	327.0Aa	334.0Aa	56.0Aa	49.0Ba
866035	376.0Aa	247.0Bb	962.0Aa	937.0Ab	83.0Aa	75.0Ba	581.0Bb	745.0Aa	256.0Bb	343.0Aa	34.0Bb	55.0Aa
866037	329.0Aa	363.0Aa	961.0Aa	939.0Aa	88.0Aa	101.0Aa	617.0Bb	753.0Aa	292.0Bb	350.0Aa	64.0Aa	60.0Aa
866040	356.0Aa	348.0Aa	957.0Aa	951.0Aa	86.0Aa	103.0Aa	754.0Aa	701.0Ba	366.0Aa	327.0Aa	77.0Aa	52.0Ab
866041	350.0Aa	370.0Aa	967.0Aa	933.0Ab	58.0Bb	85.0Ba	725.0Aa	683.0Ba	362.0Aa	334.0Aa	66.0Aa	52.0Ab
866042	370.0Aa	367.0Aa	958.0Aa	949.0Aa	88.0Aa	86.0Ba	732.0Aa	742.0Aa	352.0Aa	358.0Aa	62.0Aa	55.0Aa
866043	336.0Aa	238.0Bb	949.0Aa	949.0Aa	89.0Aa	92.0Ba	689.0Aa	751.0Aa	325.0Aa	342.0Aa	57.0Aa	47.0Ba
866044	344.0Aa	251.0Bb	951.0Aa	948.0Aa	94.0Aa	84.0Ba	713.0Aa	725.0Aa	345.0Aa	321.0Aa	64.0Aa	41.0Bb
870025	375.0Aa	240.0Bb	954.0Aa	931.0Aa	88.0Aa	107.0Aa	692.0Aa	706.0Ba	341.0Aa	319.0Aa	65.0Aa	59.0Aa
870031	363.0Aa	323.0Aa	954.0Aa	951.0Aa	111.0Aa	87.0Ba	654.0Ba	642.0Ba	297.0Ba	297.0Aa	59.0Aa	43.0Bb
870035	367.0Aa	362.0Aa	965.0Aa	925.0Ab	67.0Bb	95.0Ba	712.0Aa	699.0Ba	329.0Aa	341.0Aa	36.0Bb	55.0Aa
870041	386.0Aa	378.0Aa	965.0Aa	939.0Ab	54.0Bb	81.0Ba	715.0Aa	718.0Ba	322.0Aa	353.0Aa	48.0Bb	71.0Aa
870051	312.0Aa	310.0Aa	958.0Aa	949.0Aa	78.0Ba	75.0Ba	691.0Aa	710.0Ba	325.0Aa	336.0Aa	60.0Aa	54.0Aa
870067	372.0Aa	371.0Aa	967.0Aa	943.0Ab	77.0Ba	81.0Ba	693.0Aa	754.0Aa	317.0Ab	358.0Aa	47.0Bb	63.0Aa
870081	356.0Aa	251.0Bb	962.0Aa	949.0Aa	75.0Bb	111.0Aa	648.0Bb	763.0Aa	304.0Bb	353.0Aa	56.0Aa	53.0Aa
870085	340.0Aa	332.0Aa	953.0Aa	942.0Aa	53.0Bb	80.0Ba	703.0Aa	729.0Aa	346.0Aa	338.0Aa	60.0Aa	46.0Bb
870095	340.0Aa	338.0Aa	960.0Aa	943.0Aa	100.0Aa	77.0Ba	676.0Aa	708.0Ba	311.0Ba	332.0Aa	58.0Aa	51.0Aa
1F305	369.0Aa	362.0Aa	957.0Aa	952.0Aa	72.0Ba	84.0Ba	630.0Bb	700.0Ba	293.0Ba	326.0Aa	45.0Ba	53.0Aa
BRS 610	356.0Aa	352.0Aa	965.0Aa	958.0Aa	71.0Ba	83.0Ba	689.0Aa	692.0Ba	328.0Aa	301.0Aa	53.0Aa	43.0Ba
XBS60329	355.0Aa	346.0Aa	966.0Aa	941.0Ab	83.0Aa	90.0Ba	667.0Ab	735.0Aa	318.0Ab	364.0Aa	53.0Aa	57.0Aa

continue...

continuation...

p-value						
Hybrids	<0.001	<0.001	<0.001	0.004	<0.001	<0.001
Climate	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
Hybrids × Climate	<0.001	<0.001	0.004	<0.001	<0.001	<0.001
SEM[7]	19.6	8.2	8.6	23.0	13.8	4.8

[1]DM: dry matter; [2]OM: organic matter; [3]CP: crude protein; [4]NDF: fiber in neutral detergent; [5]FDA: fiber in acid detergent; [6]LIG: lignin;
[7]SEM: standard error of the mean. Uppercase letters in the columns compare hybrids within the cluster and lowercase letters in the rows compare climates.
Means followed by the same capital letters in the same column do not differ by the Scott-Knott procedure, at the level of 5% probability, and the same lowercase letters in the same row do not differ by the Scott-Knott procedure, at the level of 5% probability.

For CP content in BSh climate, sorghum hybrids 866005, 866019, 866033, 866034, 866035, 866037, 866040, 866042, 866043, 866044, 870025, 870031, 870095 and XBS60329 formed a group with the highest ($p < 0.05$) CP averages, ranging from 83 to 111 g kg^{-1} DM. The other sorghum hybrids (866041, 870035, 870041, 870051, 870067, 870081, 870085, 1F305 and BRS 610) were grouped with lower CP content average ranging from 53 to 78 g kg^{-1} DM. The lower CP content of sorghum hybrids in BSh compared Aw climate was mainly due to the smaller portion of panicles and leaves observed. In addition, the CP content of sorghum hybrids in both climates (means of 108 and 90 g kg^{-1} DM to Aw and BSh, respectively) was high compared to CP observed by Lyons et al. (2019) evaluating sorghum cultivars harvested at different growth stages (mean 80 g kg^{-1} DM).

The highest NDF average ($p < 0.05$) in BSh climate was observed in sorghum hybrids 866005, 866019, 866034, 866040, 866041, 866042, 866043, 866044, 870025, 870035, 870041, 870051, 870067, 870085, 870095, BRS 610 and XBS60329 ranging from 667 to 754 g kg^{-1} DM. Sorghum hybrids 866033, 866035, 866037, 870031, 870081 and 1F305 formed a group with lower averages for NDF in BSh, ranging from 581 to 654 g kg^{-1} DM.

In Aw climate, sorghum hybrids 866005, 866019, 866033, 866034, 866035, 866037, 866042, 866043, 866044, 870067, 870081, 870085 and XBS60329 were grouped with the highest ($p < 0.05$) NDF averages, ranging from 725 to 783 g kg^{-1} DM. Sorghum hybrids 866040, 866041, 870025, 870031, 870035, 870041, 870051, 870095, 1F305 and BRS 610 formed a group with lower averages for NDF in Aw, ranging from 642 to 718 g kg^{-1} DM. The hybrids that had higher similar average

NDF in both climates were 866005, 866042, 866043, 866044, 870067 and 870085, with averages ranging between 684 and 757 g kg^{-1} DM.

The lowest NDF content in climate Aw occurred due to the lower stem production, since it is in this fraction of the plant where most of the fibrous carbohydrates are concentrated. However, the NDF average values in both climates were higher than those recommended by Van Soest (1994); he stated that the NDF content must be between 500 and 600 g kg^{-1} DM. The levels observed were higher than those found by Lima et al. (2017), who evaluated 24 genotypes of forage sorghum in four Brazilian municipalities and reported averages ranging from 436 to 657 g kg^{-1} DM, however similar to those found by Paula, Abreu, Zandonadi, Litz and Albuquerque (2017), who evaluated 25 sorghum varieties in Uberlândia, Minas Gerais, Brazil and observed average NDF values in the harvest varying between 80 and 582 g kg^{-1} DM.

For the ADF content in BSh climate BSh, the hybrids 866005, 866019, 866033, 866034, 866040, 866041, 866042, 866043, 866044, 870025, 870035, 870041, 870051, 870067, 870085, BRS 610 and XBS60329 were grouped with the highest ($p < 0.05$) ADF content average, ranging from 317 to 366 g kg^{-1} DM. The other sorghum hybrids (866035, 866037, 870031, 870081, 870095, 1F305 and BRS 610) formed a group with lower ADF content average, ranging from 256 to 311 g kg^{-1} DM. In Aw climate, there was no significant difference between others hybrids ($p > 0.05$) for ADF, ranging from 297 to 364 g kg^{-1} DM. The hybrids with the highest ADF content in Aw climate were 866005, 866019, 866033, 866034, 866040, 866041, 866042, 866043, 866044, 870025, 870035, 870041, 870051, 870085, BRS 610 and XBS60329, with averages ranging from 301 to 366 g kg^{-1} DM. As with the NDF, the higher stem share in climate Aw contributed to a higher ADF content. The ADF content observed in both locations were lower than presented by Lima et al. (2017) of 263 to 433 g kg^{-1} DM, however similar to ADF observed by Paula et al. (2017) of 273 to 444 g kg^{-1} DM.

In BSh climate, sorghum hybrids 866005, 866019, 866034, 866037, 866040, 866041, 866042, 866043, 866044, 870025, 870031, 870051, 870081, 870085, 870095, BRS 610 and XBS60329 were grouped with higher ($p < 0.05$) average LIG content, ranging from 53 to 66 g kg^{-1} DM. Sorghum hybrids 866033, 866035, 870035, 870041, 870067 and 1F305 formed a group with lower LIG content averages ($p < 0.05$), ranging from 34 to 48 g kg^{-1} DM. In Aw climate, sorghum hybrids 866019, 866033, 866034, 866037, 866040, 866041, 866042, 870025, 870035, 870041, 870051, 870067, 870081, 870095, 1F305 and XBS60329 were grouped with higher LIG content averages, ranging from 51 to 71 g kg^{-1} DM. In a second group with lower averages, hybrids 866005, 866034, 866043, 866044, 870031, 870085 and BRS 610 were grouped with the lowest average values, ranging from 38 to 49 g kg^{-1} DM.

The LIG content found in climates BSh and Aw are similar to those found by Vinutha, Anil Kumar, Blümmel and Srinivasa Rao (2017), 35.9 to 47 g kg^{-1} DM in 36 improved sorghum lines studied in Patancheru, India. The hybrids that had lower levels of LIG in the present study stood out from the others, because according to Traxler et al. (1998), LIG is indigestible and acts to reduce the proportion of potentially digestible fiber in the fraction in fodder, acting as a physical barrier to limit the penetration of microorganisms.

Conclusions

Regarding agronomic characteristics, hybrids 870031, 870035, 870085, 870095, 1F305 and BRS 610 showed higher average values of green and dry matter production in the two climates evaluated, demonstrating their adaptation to different cultivation sites. However, hybrids 870031, 870095 and 1F305 are more suitable for cultivation because, in addition to presenting high yields of fresh and dry matter, they showed good nutritional quality in the two climates evaluated, showing greater adaptability.

The semi-arid region of the State of Piauí, BSh climate which presents a high climatic instability and low rainfall at certain times of the year for maize cultivation, proved to be favorable for forage sorghum production. The forage sorghum also presented agronomic characteristics similar to those found in semi humid climate Aw, a favorable region for maize cultivation. In addition, the tested hybrids showed good chemical characteristics, so the BSh climate has great exploratory potential for the cultivation of forage sorghum.

Acknowledgments

The authors are very grateful to the Coordination for the Improvement of Higher Education Personnel (CAPES) for financial support throughout the development of the research, and to Embrapa Milho e Sorgo de Sete Lagoas - MG for providing the sorghum hybrid seeds.

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