CHILEANJAR
CHILEAN JOURNAL of AGRICULTURAL RESEARCH

RESEARCH

Sesame production and composition compared with conventional forages

Diego Sousa Amorim[1], Ricardo Loiola Edvan[2], Romilda Rodrigues do Nascimento[2*], Leilson Rocha Bezerra[3], Marcos Jácome Araújo[2], Alex Lopes da Silva[4], Luciana Viana Diogénes[3], and Ronaldo Lopes de Oliveira[5]

[1]Universidade Federal do Ceará, Departamento de Zootecnia, Fortaleza, Ceará, 60020-181, Brasil.
[2]Universidade Federal do Piauí, Departamento de Zootecnia, Bom Jesus, Piauí, 64900-000, Brasil.
[*]Corresponding author (romilda0155@hotmail.com).
[3]Universidade Federal de Campina Grande, Centro de Saúde e Tecnologia, Patos, Paraíba, 58708-110, Brasil.
[4]Universidade Federal da Paraíba, Departamento de Zootecnia, Areia, Paraíba, 58397-000, Brasil.
[5]Universidade Federal da Bahia, Faculdade de Medicina Veterinária e Zootecnia, Salvador, Bahia, 4011, Brasil.

Received: 14 June 2019; Accepted: 18 August 2019; doi:10.4067/S0718-58392019000400586

ABSTRACT

Sesamum indicum L. has the potential to be cultivated as a forage plant in hot and dry climate regions, and it can be used to increase the food security of a herd. The objective of this study was to evaluate growth, production, and chemical composition of *S. indicum* compared with conventional forages used for silage production. The experiment used a randomized complete block design with split-plots related to time and four replicates per treatment. The plots consisted of four treatments (*Zea mays* L., *Helianthus annuus* L., *Pennisetum glaucum* [L.] R. Br., and *S. indicum*), and the subplots were two evaluation periods (2014 and 2016 harvests). Dry forage biomass production differed among the species in the 2014 harvest with values of 25 530, 12 190, 9408, and 9250 kg ha^{-1} for *Z. mays*, *S. indicum*, *H. annuus*, and *P. glaucum*, respectively. Maize had a greater variation in forage production between the 2 yr, followed by *S. indicum*. There were higher dry matter (DM) contents ($P < 0.0001$) for *Z. mays* and *S. indicum* (404.5 and 251.7 g kg^{-1}, respectively). Regarding crude protein, *H. annuus* and *S. indicum* had levels of 167.2 and 117.7 g kg^{-1}, respectively. According to the results, it can be inferred that sesame, like millet, provides greater feeding security for ruminant herds in regions with irregular rainfall.

Key words: Animal nutrition, corn, millet, sunflower, sesame, tropical.

INTRODUCTION

Ruminant feeding in the tropics is based on cultivated or native pastures, which are influenced by two distinct periods, rainy and dry. During the rainy season, available feed is abundant and exhibits good nutritional quality, while during the dry season, roughage availability and quality are reduced. Storing forage as silage is an excellent alternative to maintain good quality and availability during the forage shortage period and supply moist and palatable feed during pasture scarcity; this provides higher security for the herds (Silva et al., 2016; Wilkinson and Rinne, 2017).

Several forage species can be used, especially corn (*Zea mays* L.), which usually produces well-preserved silage because of its adequate dry matter (DM) and soluble carbohydrate contents and low buffer capacity. While corn is considered standard silage, its production and quality are uncertain because it is strongly influenced by water availability (Neumann et al., 2017). Sunflower (*Helianthus annuus* L.) and millet (*Pennisetum glaucum* [L.] R. Br.) have been widely used in animal feeding as silage, but they have low DM levels and high buffering power and pH in the ensiled material. Although sunflower and millet are options, other forage alternatives are sought that provide greater security to complete the production cycle and at the same time require less precipitation. Among forages with higher tolerance to water stress, sesame (*Sesamum indicum* L.) is quite adapted to this type of situation. Sesame is widely cultivated in northeast Brazil by family farmers to extract vegetable oil for human and animal consumption (Silva et al., 2014) and as an alternative forage plant, which provides greater food security to cattle ranchers.

It was hypothesized that sesame has the potential to be cultivated for silage forage, not only as an agricultural species, but along with crops already established for this purpose, such as corn, millet, and sunflower. Sesame can show better production adaptability between harvests in a tropical climate environment than corn and other forage species of conventional agriculture for silage production; this offers greater food security for the producers of these regions. Therefore, the objective of the present study was to evaluate growth, production, and chemical composition of sesame compared with forages usually used for silage production.

MATERIALS AND METHODS

Local conditions and experimental design

The experiment was carried out at the Federal University of Piauí, Campus Professor Cinobelina Elvas, in Bom Jesus, State of Piauí (09°04'28" S, 44°21'31" W; 277 m a.s.l.), Brazil. Temperature and precipitation data during the months of the experiment (January to April 2014 and January to April 2016) were obtained from the Bom Jesus meteorological station on the National Meteorological Institute (INMET) website (Figure 1).

The experiment was carried out from January to April 2014 (2014 harvest) and January to April 2016 (2016 harvest), and the crops were cultivated on dry land. To establish the crops, one plowing and two harrowing cycles were done to prepare the soil. The experimental area was 144 m^2 divided into 16 plots of 5 m^2 each, separated by uncultivated 1 m wide spaces, and the total size of each plot was 9 m^2. The plot size was in accordance with the recommendation made by Sousa et al. (2016) for agricultural crops.

Planting and harvesting

The forage species were planted in six rows with 0.7 m row spacing in each plot. Seeds were sown on 1 January 2014 and 1 January 2016 in 3 cm deep furrows with a seeding density of 30 seeds m^{-1} for the forage species under study: corn (*Zea mays* L.) 'Bandeirante', sunflower (*Helianthus annuus* L.) 'BRS 324', millet (*Pennisetum glaucum* [L.] R. Br.) 'BRS 1501', and sesame (*Sesamum indicum* L.) 'CNPA G2'. Plants of all the studied species were thinned 30 d after planting to reach a density of 20 plants m^{-1}. The same conditions were maintained for all the studied species.

Fertilization was carried out during the 2 yr according to the soil analyses shown in Table 1 and following the recommendations made by Barcellos et al. (2007). At planting in both years, 40 kg P ha^{-1} (single superphosphate, 18% P_2O_5) and 60 kg K ha^{-1} (potassium chloride, 48% KCl) were applied, and 70 kg N ha^{-1} (urea, 45% N) was applied 45 d after planting.

The time to harvest and determine the evaluations was according to the seed maturation of the forage species. The hard farinaceous grain stage was considered for corn, whereas for millet, sesame seed, and sunflower, it was the yellow color of the head with the leaves showing brown coloring and specifically when the grain was pasty to farinaceous. All forage species were cut 10 cm from the soil, and the aim was to maintain the same conditions for all the species.

Growth characteristics and morphological components

At each harvest (2014 and 2016), growth characteristics were evaluated as follows: live plants (%), plant height (m), and plant lodging (%). Live plants were the count of total live plants and the tiller area of the useful area. Height considered the mean height of 10 randomly selected plants in the plot area and measured with a 25 m measuring tape (Cescorf, Porto

Table 1. Soil chemical analysis of the area where the four forage species were planted for 2014 and 2016 harvests.

pH*	P	K	Na	Ca	Mg	Al	H+Al	SB	CEC-t	CEC-T	V	m
	mg dm^{-3}			cmol dm^{-3}							%	
5.78	29.6	84.0	-	2.8	1.2	0.1	3.3	4.3	4.3	7.5	56.0	2.3

*pH in water: 1:2.5 ratio; P-K-Na: Mehlich[1] extractor; Ca-Mg-Al: extractor KCl[1] mol^{-1}; H+Al: extractor SMP; SB: sum of exchangeable bases; CEC-t: effective cation exchange capacity; CEC-T: effective cation exchange capacity at pH 7.0; V: basal saturation index; m: Al saturation index.

Alegre, Rio Grande do Sul, Brazil). The plant lodging percentage was evaluated by counting the number of lodged plants in the plot.

To evaluate the morphological characteristics, two plants were randomly selected from each plot; leaf (g kg^{-1}), stem (g kg^{-1}), dead material (g kg^{-1}), inflorescence (g kg^{-1}; consisting of seeds), and leaf/stem ratio were measured. The material was individually weighed to obtain green weight and was then placed in a forced ventilation oven at 55 °C for 72 h to obtain dry weight. The percentage of morphological components based on DM was then calculated. Using the dry biomass data, the leaf/stem ratio was calculated by dividing leaf weight by stem weight. All evaluations were carried out in both years (2014 and 2016).

Productive characteristics and chemical composition

The production of green forage biomass, dry forage biomass, leaf biomass, stem biomass, dead biomass, and inflorescence biomass were evaluated at the 2014 and 2016 harvests. Plants within the useful area were manually cut and weighed to calculate green biomass. Afterward, they were placed in a forced ventilation oven at 55 °C for 72 h to determine dry weight and obtain the morphological component and forage biomass (kg ha^{-1}) production.

Forage species samples (triplicate) were processed as 2-5 cm particles in a stationary forage machine (GT-2000L Garthen, Navegantes, Santa Catarina, Brazil), and a 300 g sample was removed to determine pre-dried biomass. Pre-dried samples were ground in a knife-type Wiley Mill (Tecnal, Piracicaba, São Paulo, Brazil) with a 1.0 mm mesh sieve, packed, and sealed in 250 mL disposable round plastic food pots (Prafesta, Mairiporã, São Paulo, Brazil) with lids.

Laboratory analyses were performed for DM, crude protein (CP) concentration (N × 6.25) (method 981.10; AOAC, 1990), ash (942.05; AOC, 1990), and ether extract (EE) (920.29; AOAC, 1990). To determine the content of neutral detergent fiber (NDF) and acid detergent fiber (ADF), the methodology described by Van Soest et al. (1991) was used along with the modifications proposed in the Ankom device manual (Ankom Technology Corporation, Macedon, New York, USA). Non-fibrous carbohydrates (NFC) were determined by the equation indicated by Mertens (1997): NFC = 100 – (CP + NDF + ash + EE). The ADF residue was subsequently analyzed for acid detergent lignin (ADL) by cellulose solubilization with sulfuric acid according to AOAC (2002). Hemicellulose was calculated as the difference between NDF and ADF and cellulose content as the difference between ADF and the ADL. Total digestible nutrients (TDN) were calculated according to the equation proposed by Capelle et al. (2001): TDN = 99.39 – 0.7641 × NDF.

Experimental design and statistical analysis

The experiment used a randomized complete block design with split-plots related to time and four replicates for growth, morphological, and production characteristics. Plots consisted of four different forage species (corn, sunflower, millet, and sesame) and subplots for two evaluation periods (2014s and 2016s harvests). Samples were taken in both the 2014 and 2016 harvests. To evaluate the chemical composition, the experiment used a randomized complete block design with four replicates and with data from the 2014 harvest. The results were statistically analyzed by ANOVA and means comparison by Tukey's test at $P < 0.05$ with the Sisvar 5.6 software (Ferreira, 2011).

RESULTS

Growth characteristics

There was an interaction effect (Table 2) between the forage species and harvests on the growth variables. Millet and sesame showed a higher percentage of live plants ($P < 0.0001$) compared with corn and sunflower in the 2014 harvest. However, in the 2016 harvest, there was no difference between the species and the percentage of live plants. Sesame, millet, and corn were higher ($P = 0.0046$) for plant height in the 2014 harvest. However, millet and sesame were higher for the 2016 harvest, with heights of 1.45 m and 1.34 m, respectively. Corn and sunflower showed similar values, but these were lower than the other species. Sesame and sunflower showed higher percentage of plant lodging ($P = 0.0004$) in the 2014 harvest. As for the 2016 harvest, there was no difference among the studied species for plant lodging.

Morphological components

The 2016 harvest was superior to the 2014 harvest ($P < 0.0001$) (Table 3) for most species regarding leaf percentage, except for sunflower that did not show a significant difference between harvests. However, species did not differ for leaf

Table 2. Growth characteristics of sesame and forage species used to produce silage for 2014 and 2016 harvests.

Species	Harvest 2014	Harvest 2016	Mean	Species	Harvest	Species × Harvest	SEM
Live plants (%)							
Corn	65.5bB	82.5aA	74.0				
Millet	100.0aA	99.2aA	99.6				
Sunflower	53.0bB	100.0aA	76.5	P < 0.0001	P = 0.1280	P < 0.0001	1.70
Sesame	100.0aA	86.7bA	93.3				
Mean	79.6	92.1					
Plant height (m)							
Corn	1.7aA	0.7bB	1.2				
Millet	1.7aA	1.4aA	1.6				
Sunflower	0.7aB	0.8aB	0.8	P < 0.0001	P < 0.0001	P = 0.0046	0.06
Sesame	1.9aA	1.3bA	1.6				
Mean	1.5	1.1					
Plant lodging (%)							
Corn	9.9aB	11.1aA	10.5				
Millet	12.7aB	9.4aA	11.0				
Sunflower	54.7aA	0.0bA	27.3	P = 0.0384	P < 0.0001	P = 0.0004	3.02
Sesame	32.3aA	7.8bA	16.5				
Mean	27.4	5.34					

SEM: Standard error of the mean.
Means followed by different lowercase letters on the same line differ by Tukey's test (P < 0.05); means followed by different uppercase letters in the same column differ by Tukey's test (P < 0.05).

components in the 2014 harvest. Corn and sesame showed higher leaf percentages in the 2016 harvest, and the stem component was higher in the 2014 harvest (P = 0.0004) compared with the 2016 harvest. Sesame produced more stem and sunflower had a lower percentage of this component (P < 0.0001) among the studied species.

Corn (P < 0.0001) had the highest value among the crops for the morphological dead material component. Sunflower, millet, and sesame showed no difference between harvests. Sesame did not produce dead material in the two studied harvests.

Corn, millet, and sesame showed higher leaf/stem (P < 0.0001) ratios in the 2016 harvest compared with the 2014 harvest. Sunflower showed the highest leaf/stem ratio (0.58) in the 2014 harvest. The other species did not differ in the 2014 harvest. Corn was superior compared to the other studied forage species for leaf/stem ratio in the 2016 harvest.

Productive characteristics and chemical composition

The green forage biomass production of corn varied (P = 0.0320) with values of 58 000 and 27 300 kg ha^{-1} for the 2014 and 2016 harvests, respectively (Table 4). Sesame, millet, and sunflower showed no variation in dry forage biomass production between harvests. There was no difference among species for green forage biomass production in the 2014 harvest. However, millet, sesame, and corn in the 2016 harvest yielded higher green forage biomass (P = 0.0320). For dry forage biomass production, there was no difference between the sunflower and sesame crops. Corn had higher dry forage biomass production in the 2014 harvest compared with the 2016 harvest, and it was different from millet, which obtained higher dry biomass forage production in the 2016 harvest.

Corn exhibited the highest dry forage biomass production (25 530 kg ha^{-1}) in the 2014 harvest. However, sesame, sunflower, and millet did not differ with values of 12 190, 9480, and 9250 kg ha^{-1}, respectively. Millet and sesame in the 2016 harvest showed higher dry forage biomass yields, but sesame did not differ from sunflower and corn.

There was no difference between harvests for dead biomass production (P < 0.0001). Corn exhibited higher dead biomass production (P = 0.0582) and sesame produced no dead material, regardless of the harvest. As for inflorescence biomass production (P < 0.0001), there was a difference between harvests for corn, millet, and sunflower; corn showed higher inflorescence biomass production (P < 0.0001) in the 2014 harvest. Inflorescence biomass production (P < 0.0001) in the 2016 harvest was higher for millet, which did not differ from sunflower and corn.

Table 3. Morphology of sesame and forage species used to produce silage for 2014 and 2016 harvests.

	Harvest						
Species	2014	2016	Mean	Species	Harvest	Species × Harvest	SEM
			Leaf (g kg^{-1})				
Corn	128.1bA	326.3aA	227.2				
Millet	144.3bA	212.2aB	178.3				
Sunflower	135.2aA	113.2aC	124.2	P = 0.0007	P < 0.0001	P < 0.0001	1.04
Sesame	80.4bA	301.8aA	191.1				
Mean	122.0	238.4					
			Stem (g kg^{-1})				
Corn	410.2	316.1	363.2C				
Millet	578.2	494.9	536.6B				
Sunflower	247.7	187.5	217.6D	P < 0.0001	P = 0.0004	P = 0.9346	1.33
Sesame	663.3	585.7	624.5A				
Mean	474.9a	396.0b					
			Dead material (g kg^{-1})				
Corn	73.4bA	195.2aA	134.3				
Millet	89.5aA	44.5aB	67.0				
Sunflower	96.9aA	65.1aAB	81.0	P < 0.0001	P = 0.3383	P < 0.0001	0.81
Sesame	0.0aB	0.0aC	0.0				
Mean	64.9	76.2					
			Inflorescence (g kg^{-1})				
Corn	388.1aAB	162.2bAB	275.1				
Millet	187.7aC	248.1aA	217.9				
Sunflower	520.0aA	187.0bAB	353.5	P = 0.0002	P < 0.0001	P = 0.0002	1.80
Sesame	256.2aAB	57.3bC	156.8				
Mean	338.0	163.7					
			Leaf/stem ratio				
Corn	0.3bB	1.0aA	0.6				
Millet	0.2bB	0.4aB	0.3	P < 0.0001	P < 0.0001	P < 0.0001	0.03
Sunflower	0.5aA	0.6aB	0.5				
Sesame	0.1bB	0.5aB	0.3				
Mean	0.3	0.6					

SEM: Standard error of the mean.
Means followed by different lowercase letters on the same line differ by Tukey's test (P < 0.05); means followed by different uppercase letters in the same column differ by Tukey's test (P < 0.05).

The chemical composition of the forage species was only evaluated in the 2014 harvest (Table 5). The highest DM content (P < 00001) was observed for corn and sesame. Millet and sunflower showed a lower concentration. Ash content (P = 0.0077) was higher in millet than in corn, which had the lowest concentration for this variable. Neutral detergent fiber (NDF; P < 0.0001) ranged from 441.7 to 738.4 g kg^{-1}. It was verified that millet and corn showed higher fractions of NDF (P < 0.0001), differing from sesame and sunflower.

The ADF concentrations in sesame and millet did not differ, while sunflower and corn obtained a lower concentration (P = 0.0153). Sunflower and sesame had the highest CP contents (P < 0.0001) and had mean values of 167.2 and 117.7 g kg^{-1}, respectively. However, millet and corn had the lowest CP contents with means of 91.5 and 66.7 g kg^{-1}, respectively. The highest EE concentration was found in the sunflower and sesame crops, 146.1 and 105.4 g kg^{-1}, respectively, while corn and millet showed lower EE concentrations and did not differ.

The non-fibrous carbohydrate content (P = 0.0167) ranged from 75.0 to 159.2 g kg^{-1} in the studied species, and corn and sesame showed higher concentrations. Cellulose content (P < 0.0001) did not differ among forages. Millet exhibited higher ADL content (P = 0.0171), but corn and sesame were similar. Corn, millet, and sesame did not differ for the hemicellulose content (P < 0.0001), but sunflower had the lowest content. For total digestible nutrients (P < 0.0001), sunflower and sesame exhibited higher concentrations compared with corn and millet.

Table 4. Productive characteristics of sesame and forage species used to produce silage between harvests.

Species	Harvest 2014	Harvest 2016	Mean	Species	Harvest	Species × Harvest	SEM
			Green forage biomass production (kg ha^{-1})				
Corn	58000aA	27300bAB	42600				
Millet	49700aA	54200aA	51900				
Sunflower	43500aA	25400aB	34400	P = 0.1096	P = 0.0893	P = 0.0320	3520
Sesame	43300aA	52200aAB	47700				
Mean	48600	39700					
			Dry forage biomass production (kg ha^{-1})				
Corn	25500aA	7900bB	16700				
Millet	9400bB	17800aA	13600				
Sunflower	9200aB	7500aB	8400	P = 0.0121	P = 0.0749	P = 0.0002	1150
Sesame	12100aB	10800aAB	11100				
Mean	14100	11000					
			Leaf biomass production (kg ha^{-1})				
Corn	3200aA	2600aAB	2900				
Millet	1300bAB	3800aA	2600				
Sunflower	1200aAB	800aC	1000	P = 0.0148	P = 0.0418	P = 0.0190	280
Sesame	900bB	3000aAB	1900				
Mean	1700	2500					
			Stem biomass production (kg h^{-1})				
Corn	10400aA	2500bBC	6400				
Millet	5500aBC	8900aA	7200				
Sunflower	2300aC	1400aC	1800	P = 0.0004	P = 0.0517	P = 0.0012	590
Sesame	8000aAB	6400aAB	7200				
Mean	6500	4800					
			Dead biomass production (kg ha^{-1})				
Corn	1800	1400	1600A				
Millet	800	400	600B				
Sunflower	800	400	600B	P < 0.0001	P = 0.0582	P = 0.7200	90
Sesame	0	0	0C				
Mean	800a	600a					
			Inflorescence biomass production (kg ha^{-1})				
Corn	9900aA	1300bAB	5600				
Millet	1700bB	4500aA	3100				
Sunflower	4700aB	1400bAB	3000	P = 0.0043	P = 0.0002	P < 0.0001	450
Sesame	3100aB	500aB	1800				
Mean	4900	1900					

SEM: Standard error of the mean.
Means followed by different lowercase letters on the same line differ by Tukey's test (P < 0.05); means followed by different uppercase letters in the same column differ by Tukey's test (P < 0.05).

DISCUSSION

Growth characteristics and morphological components

The millet and sesame species showed a higher percentage of live plants, which means less agronomic management is needed, such as plant thinning and weed control, for the adequate development of the crop because it increases the plant cover area in the soil; in addition, it is correlated with greater forage biomass production. Sunflower showed lower height due to the greater number of plants.

The high plant lodging percentage of sunflower and sesame in the 2014 harvest can be attributed to higher rainfall at the end of the productive cycle. According to Demétrio et al. (2012), lodging is a complex phenomenon and its expression depends on genetic factors related to climate factors, soil, adopted agronomic practices, and damage caused by pests and

Table 5. Chemical composition of sesame and forage species used for silage production in the 2014 harvest.

	Forage species					
Nutrients, g kg^{-1} DM	Corn	Millet	Sunflower	Sesame	SEM	P values
Dry matter, g kg^{-1} as feed	404.5a	175.4c	196.5c	251.7b	0.80	P < 0.0001
Ash	57.5b	79.8a	79.0ab	60.8ab	0.42	P = 0.0077
Neutral detergent fiber	699.9a	738.4a	441.7c	562.4b	1.23	P < 0.0001
Acid detergent fiber	341.7b	439.0a	347.7b	369.9ab	1.81	P = 0.0153
Crude protein	66.7d	91.5c	167.2a	117.7b	0.43	P < 0.0001
Ether extract	16.5c	15.0c	146.1a	105.4b	0.63	P < 0.0001
Non-fibrous carbohydrates	159.2a	75.0b	123.8ab	153.5a	1.58	P = 0.0167
Acid detergent lignin	27.6b	59.0a	42.0ab	31.4b	0.58	P = 0.0171
Cellulose	314.1a	380.0a	305.7a	338.5a	1.88	P = 0.0637
Hemicellulose	358.2a	299.4ab	94.0b	192.5ab	2.01	P < 0.0001
Total digestible nutrients	459.0c	429.6c	656.3a	564.1b	0.94	P < 0.0001

SEM: Standard error of the mean.
Means followed by different lowercase letters in the same row differ by Tukey's test (P < 0.05).

diseases. The high plant lodging percentage for sunflower in the 2014 harvest may have influenced the lowest percentage of live plants in that year (Table 2).

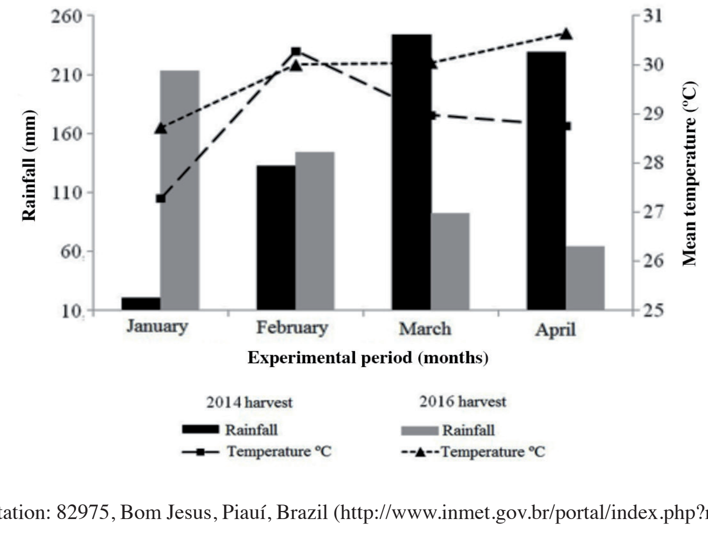
The corn, millet, and sunflower species exhibited a high percentage of dead material (Table 3); this fact can be explained by irregular rainfall (Figure 1) in the region that compromises the phenological development of these species. The high amount of dead material in corn might reduce the quality of forage produced and compromise the chemical composition.

A higher percentage of leaves and inflorescences (presence of grains) provides better nutritive value to the forage (Moraes et al., 2013). A higher percentage of leaves and inflorescences (presence of grains) was observed in corn and sunflower in both years. The presence of grains is directly related to the greater fermentative capacity and nutritional value of the produced silage (Simão et al., 2015).

Regarding total leaf DM, sesame showed high leaf abscission, which was different from corn that retained dead leaves on the plant. This characteristic of sesame is indicative of adaptation to regions with irregular precipitation (tropical or subtropical climate) because even with below-average rainfall it can stay longer in the field. In addition, it was among the species that took the longest time to reach the time to harvest, approximately 100 d.

The lower stem percentage in sunflower might confer lower fiber content in its chemical composition. According to Perazzo et al. (2014), the stem presents high fiber content compared with the leaf, thus compromising digestibility. The

Figure 1. Precipitation data (mm) and mean temperature (°C) from 11 January to 21 April 2014 and from 10 January to 14 April 2016.



Meteorological station: 82975, Bom Jesus, Piauí, Brazil (http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep).

plant's nutritional value can be compromised when stem production is greater than leaf percentage. The part of the plant with the highest protein and carbohydrate content is the seed, giving a significant value to the produced forage because it allows a better quality plant.

Sunflower and corn showed higher leaf/stem ratios in the 2014 and 2016 harvests, respectively. This indicates the better quality of forage produced by these plants. According to some authors, a greater participation of the leaf component is preferable because this portion of the plant is usually more nutritive compared with the stem (Santos et al., 2013; Parente et al., 2014).

Productive characteristics and chemical composition

Green forage biomass production is a result of the greater adaptability of millet, sunflower, and sesame when compared with corn under irregular rainfall conditions (Figure 1). When rainfall is available at the end of the productive cycle, there is no difference between the species in green biomass production. When there is no rainfall during the last 2 mo of the cycle, millet and sesame are superior. Vital et al. (2015) found values of 7750 and 3000 kg ha^{-1} of green and dry forage biomass production in millet for silage. Millet shows greater savings in silage production than *Glycine max* (Jahanzad et al., 2015) because soy, like corn, has a high market value. This explains why the production of millet and sesame silage is more profitable for animal production, that is, they are crops with lesser market value.

The DM content of a forage crop is considered as the main factor that determines silage quality according to Vieira et al. (2013a). The low DM content of sunflower and millet was related to the studied variety, which exhibited high moisture even at the cut-off point in a certain portion of the plant, such as the stem, probably due to physiological maturity, that is, in the reproductive stage when the back of the heads of sunflower plants turn yellow. Sesame had DM content of 251.7 g kg^{-1}, which is within the recommended range (250 to 350 g kg^{-1}) at harvest for silage forage (Mota et al., 2011).

According to Carvalho et al. (2015), ash content indicates the value of macro and micro minerals in forage.

It is worth noting that NDF is a characteristic that is directly related to the rate of passage of feed through the digestive tract, and if NDF is lower, DM intake is higher. Likewise, the NDF content is directly related to factors such as cultivar cycle, night temperature, and soluble carbohydrate content.

The ADF values in the present study were higher than those found by Vieira et al. (2013b), who reported approximate mean values of 292.9 g kg^{-1} for several corn genotypes. The ADF is related to forage digestibility because it contains the highest proportion of ADL, which is the fraction of the fiber that exhibits complete indigestibility. In addition, it is an indicator of the energy value of the material, that is, if ADF is lower, the energy value of the forage is higher.

Except for corn, all the other crops had CP values greater than 70 g kg^{-1}, which is the minimum level for the adequate functioning of rumen microbiota (Viana et al., 2012). It can be noted that sesame is an alternative feed rich in CP, and it can increase the amount of this nutrient in the animal diet. It might also be related to the higher leaf/stem ratio of these species, which resulted in considerable CP content because the leaves, especially the young ones, have a high amount of this component in their composition (Pinho et al., 2013b).

The high EE content of sunflower and sesame is related to the fact that they are vegetables that store energy in the grain as oil. Forages with higher EE contents (fat) tend to have higher values of total digestible nutrients because fat provides 2.25 times more energy than carbohydrates. According to Azevedo et al. (2011), total fat in a diet for ruminants in most situations should not exceed 60 to 70 g kg^{-1} DM because it can determine reductions in ruminal fermentation, fiber digestibility, and passage rate. Thus, the use of forages such as sunflower and sesame seeds with high EE levels in ruminant diets has limitations, indicating a possible need for association with other bulky feeds.

The non-fibrous carbohydrate (NFC) content was higher in corn and sesame, probably due to starch-rich substrates and sugars, the corn components of NFC. According to McDonald et al. (1991), the minimum soluble carbohydrate forage value necessary to ensure good lactic fermentation ranges from 8 to 10 g kg^{-1} DM. This can favor sesame during ensiling because it can exhibit fermentation similar to corn that is mainly for the development of lactic acid bacteria and thus contribute to the rapid decline of pH (Tao et al., 2017). Regarding the lignin content, sesame was similar to corn, and both were lower than millet and sunflower.

The cellulose content of the forages can be directly linked to the ADF because cellulose is an important component of this fraction. This may have caused the similarity among forages. Regarding hemicellulose, sunflower had smaller amounts, which is a disadvantage because hemicellulose is one of the main substrates of fermentation (Carvalho et al., 2016). The total digestible nutrients (TDN) were higher in sunflower and sesame seeds, which may be directly related to the EE content. According to Monteiro et al. (2016), high TDN values are characteristic of noble feeds because TDN is a parameter used to quantify feed energy. Another important fact is that forages with a high number of grains tend to have higher TDN values compared with low grain forages.

CONCLUSIONS

According to the results, it can be inferred that sesame, like millet, provides greater feeding security for ruminant herds in regions with irregular rainfall.

ACKNOWLEDGEMENTS

Conceptualization: FAPEPI for the funding of the research. Amorim, D.S., Edvan, R.L., Bezerra, L.R. Data acquisition: Amorim, D.S., Silva, A.L., Nascimento, R.R., Diogénes, L.V. Data analysis: Amorim, D.S., Edvan, R.L., Araújo, M.J. Design of Methodology: Amorim, D.S., Edvan, R.L. Software development: Amorim, D.S., Edvan, R.L. Writing and editing: Amorim, D.S., Edvan, R.L., Bezerra, L.R., Oliveira, R.L.

REFERENCES

AOAC. 1990. Official methods of analysis. 15th ed. Association of Official Analytical Chemists (AOAC), Arlington, Virginia, USA.

AOAC. 2002. Official methods of analysis. 16th ed. Association of Official Analytical Chemists (AOAC), Washington DC., USA.

Azevedo, J.A.G., Valadares-Filho, S.C., Pina, D.S., Detmann, E., Valadares, R.F.D., Pereira, L.G.R., et al. 2011. Intake, total digestibility, microbial protein production and the nitrogen balance in diets with fruit by-products for ruminants. Revista Brasileira de Zootecnia 40:1052-1060.

Barcellos, A.O., Sousa, D.M.G., Martha Júnior, G.B., Vilela, L., e Barioni, L.G. 2007. Cerrado: uso eficiente de corretivos em pastagens. Embrapa Cerrados, Planaltina, Distrito Federal, Brasil.

Capelle, E.R., Valadares Filho, S.C., Silva, J.F.C., and Cecon, P.R. 2001. Estimates of the energy value from chemical characteristics of the feedstuffs. Revista Brasileira de Zootecnia 30:1837-1856.

Carvalho, A.F.G., Martin, T.N., Santos, S., Müller, T.M., e Piran Filho, F.A. 2015. Perfil agronômico e bromatológico de silagem de milho no sudoeste do Paraná. Revista de la Facultad de Agronomía 114:149-159.

Carvalho, W.G., Costa, K.A.P., Epifanio, P.S., Perim, R.C., Teixeira, D.A.A., and Medeiros, L.T. 2016. Silage quality of corn and sorghum added with forage peanuts. Revista Caatinga 29:465-462.

Demétrio, J.V., Costa, A.C.T., e Oliveira, P.S.R. 2012. Produção de biomassa de cultivares de aveia sob diferentes manejos de corte. Revista Pesquisa Agropecuária Tropical 42:V198-205.

Ferreira, D. 2011. Sisvar: a computer statistical analysis system. Ciência e Agrotecnologia 35(6):1039-1042.

Jahanzad, E., Sadeghpour, A., Hashemi, M., Keshavarz Afshar, R., Hosseini, M.B., and Barker, A.V. 2015. Silage fermentation profile, chemical composition and economic evaluation of millet and soya bean grown in monocultures and as intercrops. Grass and Forage Science 71:584-594.

McDonald, P., Henderson, N., and Heron, S. 1991. The biochemistry of silage. Chalcombe Publications, Marlow, UK.

Mertens, D.R. 1997. Creating a system for meeting the fiber requirements of dairy cows. Journal of Dairy Science 80:1463-1481.

Monteiro, I.J.G., Abreu, J.G. Cabral, L.S., Almeida, R.G., Reis, R.H.P., Behling Neto, A., et al. 2016. Ensiling of elephant grass with soybean hulls or rice bran. Semina: Ciências Agrárias 37:4203-4212.

Moraes, S.D., Jobim, C.C., Silva M.S., e Marquardt, F.I. 2013. Produção e composição química de híbridos de sorgo e de milho para silagem. Revista Brasileira de Saúde e Produção Animal 14:624-634.

Mota, Á.D.S., Rocha Júnior, V.R., Souza, A.S., Reis, S.T., Tomich, T.R., Caldeira, L.A., et al. 2011. Perfil de fermentação e perdas na ensilagem de diferentes frações da parte aérea de quatro variedades de mandioca. Revista Brasileira de Zootecnia 40:1466-1473.

Neumann, M., Leão, G.F.M., Coelho, M.G., Figueira, D.N., Spada, C.A., e Perussolo, L.F. 2017. Aspectos produtivos, nutricionais e bioeconômicos de híbridos de milho para produção de silagem. Archivos de Zootecnia 66:51-57.

Parente, H.N., Silva Junior, O.R., Bandeira, J.R., Parente, M.O.M., Rodrigues, R.C., Rocha, K.S., et al. 2014. Produtividade do sorgo forrageiro em função de quantidades crescentes de adubação fosfatada e nitrogenada. Revista Trópica: Ciências Agrárias e Biológicas 8(1):01-10.

Perazzo, A.F., Carvalho, G.G.P., Santos, E.M., Pinho, R.M., Campos, F.S., Macedo, H.O., et al. 2014. Agronomic evaluation of 32 sorghum cultivars in the Brazilian semi-arid region. Revista Brasileira de Zootecnia 43:232-237.

Pinho, R.M.A., Santos, E.M., Bezerra, H.F.C., Macedo, C.H.O., Campos, F.S., Ramos, J.P.F., et al. 2013b. Avaliação de genótipos de milheto para silagem no semiárido. Revista Brasileira de Saúde e Produção Animal, Salvador 14(3):426-436.
Santos, R.D., Pereira, L.G.R., Neves, A.L.A., Rodrigues, J.A.S., Costa, C.T.F., and Oliveira, G.F. 2013. Agronomic characteristics of forage sorghum cultivars for silage production in the lower middle San Francisco Valley. Acta Scientiarum-Animal Sciences 35:13-19.
Silva, E.B., Carneiro, M.S.S., Edvan, R.L., Coutinho, M.J., Bezerra, L.R., e Pereira, E.S. 2016. Produção de espécies forrageiras produtoras de grãos e composição química de silagens. Scientia Agraria Paranaensis 15:164-170.
Silva, J.C.A., Fernandes, P.D., Bezerra, J.R.C., Arriel, N.H.C., e Cardoso, G.D. 2014. Crescimento e produção de genótipos de gergelim em função de lâminas de irrigação. Revista Brasileira de Engenharia Agrícola e Ambiental 18:408-416.
Simão, E.P., Gontijo Neto, M.M., Santos, E.A., e Wendling, I.J. 2015. Produção de biomassa e composição bromatológica de duas cultivares de milheto semeadas em diferentes épocas. Revista Brasileira de Milho e Sorgo 14(2):196-206.
Sousa, R.P., Silva, P.S.L., e Assi, J.P. 2016. Tamanho e forma de parcelas para experimentos com girassol. Revista Ciência Agronômica 47:683-690.
Tao, L., Zhou, H., Zhang, N., Si, B., Tu, Y., Ma, T., et al. 2017. Effects of different source additives and wilt conditions on the pH value, aerobic stability, and carbohydrate and protein fractions of alfalfa silage. Animal Science Journal 88:99-106.
Van Soest, P.J., Robertson, J.B., and Lewis, B.A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polyssacharides in relation to animal nutrition. Journal of Dairy Science 74:3583-3597.
Viana, P.T., Pires, A.J.V., Oliveira, L.B., Carvalho, G.G.P., Ribeiro, L.S.O., Chagas, D.M.T., et al. 2012. Fracionamento de carboidratos e de proteína das silagens de diferentes forrageiras. Revista Brasileira de Zootecnia 41:292-297.
Vieira, V.C., Martin, T.N., Menezes, L.F.G., Assmann T., Ortiz S., Bertoncelli, P., et al. 2013a. Caracterização bromatológica e agronômica de genótipos de milho para produção de silagem. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 65:847-856.
Vieira, V.C., Martin, T.N., Menezes, L.F.G., Ortiz, S., Bertoncelli, P., and Storck, L. 2013b. Caracterização bromatológica de silagens de milho de genótipos super precoce. Ciência Rural, Santa María 43:1925-1931.
Vital, A.F.M., Santos, D., e Santos, R.V. 2015. Características agronômicas do milheto adubado com diferentes fontes orgânicas. Revista Agropecuária Técnica 36:303-309.
Wilkinson, J.M., and Rinne, M. 2017. Highlights of progress in silage conservation and future perspectives. Grass and Forage Science 73:40-52.