Fermentation profile and nutritional value of sesame silage compared to usual silages

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ABSTRACT

The objective was to evaluate the fermentation parameters, chemical composition and in situ degradability of sesame silage in comparison to usual silages. The losses, fermentation quality and chemical composition of the forages and silages were evaluated using a completely randomised design with four treatments (sesame, corn, millet and sunflower) and four replicates per treatment, the silages were produced in experimental silos. In-situ degradability was evaluated using a completely randomised design with four treatments and three replicates (animals) per treatment. The results were statistically evaluated by analysis of variance and Tukey’s test with a level of 5% of probability. Three rumen fistulated non-castrated Santa Inês rams were used. Sunflower and corn silages presented higher percentages of losses through gases ($p = .0256$). Millet silage presented higher losses by effluent ($p < .0001$). The dry matter recovery ($p < .0001$) ranged from 70.0 to 96.5% for sesame and corn silage, respectively. The dry matter content ($p = .0002$) in the silages ranged from 280.0 to 429.4 g kg$^{-1}$. The sesame silage presented loss amounts and fermentation parameters similar to those found in corn and sunflower silage. Sesame silage showed moderate dry matter (DM), content, excellent crude protein (CP) and total digestible nutrients (TDN) contents, and low lignin content. Corn silage presented higher concentration of the soluble fraction of DM ($p < .0001$). The sesame silage presented a high degradability rate of DM and it was similar to corn and millet which have great nutritional potential for ruminants feeding. Sesame has the potential to produce quality biomass and silage for animal feeding.

HIGHLIGHTS

- The sesame can be an option for silage making.
- Sesame helps to ensure sustainability by promoting lower seasonal risks in this region through the usage of silage as feed for the animals.
- Sesame also increases the productivity of livestock throughout the year, through the availability of feed for the herd mainly during the dry season of the year.

Introduction

Because of seasonality of pastures in the dry season, tropical forages do not provide enough nutrients in order to keep good productive responses by the animals. Therefore, alternatives that meet the demand of roughages in this period such as silage production (Monteiro et al. 2016) are necessary. Thus, the storage of the forage surplus from the rainy season for use in the dry season is a viable strategy for livestock.

Forage conservation processes often present losses of nutrients of various proportions and eventually these losses occur throughout the ensiling period (Valença et al. 2016). Losses in the form of gases and effluent are often related to the characteristics of the ensiled plants. The presence of effluent in the silo is undesirable and should be avoided in order to reduce damage to the fermentation process, such as the increase of proteolysis and the establishment of bacteria of the genus Clostridium (Dunière et al. 2013).

However, tropical regions are characterised by the irregularity of rainfall and the usual forage species present great difficulties to grow and to be used in the...
form of silage for ruminants feeding. Thus, corn is the most used (Zea mays L.) followed by millet (Pennisetum glaucum) and sunflower (Helianthus annuus L.). Although corn is considered the standard for silage, it has a higher dependence on rain regularity than other alternative species. Thus, sesame (Sesamum indicum L) which is considered to be resistant to drought, (Oliveira et al. 2010), can be an option for ensiling.

Sesame is widely cultivated by farmers in regions of dry climate, mainly due to its ease of planting and high forage mass in produced in these environments, when compared to other agricultural crops. Usually its cultivation is mainly focussed on the extraction of vegetable oil and human consumption (Silva et al. 2014), and for this reason the use of sesame for silage production may be a good option, because the animals do not eat sesame spontaneously by nature, but silage is seen to be consumed spontaneously.

However, there are no studies regarding sesame in animal feeding, there just is empirical evidence of sheep and goats feeding on this plant wilted. However, this plant might be supplied as ruminant feed in the conserved form, thus ensuring greater food security for periods of food shortage for livestock of regions with marked rainfall irregularities. Therefore, it is hypothesised that sesame silage might be an alternative to the silages commonly made and to the species already consecrated as potential for ensiling.

Thus, the objective of this work was to evaluate the fermentation parameters, chemical composition and in situ degradability of sesame silage in comparison to corn, millet and sunflower silages.

**Material and methods**

**Ethical considerations, site conditions and experimental design**

The study was carried out according to the recommendations described in the Guide of the National Council for the Control of Experiences in Animals (CONCEA). The Ethics Committee on Animal Experiments of the Federal University of Piauí, State of Piauí with Permit Number approved the protocol: 016-14.

The experiment was carried out from January 2014 to April 2014 at the Small Ruminants Research Unit of the Technical College of Bom Jesus, Piauí, located at the Professor Cinobelina Elvas Campus of the Federal University of Piauí. The site is located at latitude of 09°04’28” S and longitude 44°21’31” W and at an altitude of 277 m. The climate is characterised as hot and semi-humid, with minimum temperature of 18 °C, maximum temperature of 36 °C and average precipitation of 900 mm (Andrade Junior et al. 2004).

Two experiments were carried out: the first one evaluated the losses, fermentative quality and chemical composition of forages and silages in the crop of 2014 using a completely randomised design with four treatments (sesame, corn, millet and sunflower) and four replicates per treatment. The silages were produced in 3 kg experimental silos and opened after 30 days. In the second experiment, in situ degradability was evaluated using a completely randomised design with four treatments (sesame, corn, millet and sunflower silages) and three replicates (animals) per treatment with the incubation times (0, 6, 12, 24, 48, 72 and 96 h) representing the subplots. Three rumen fistulated non-castrated Santa Inês rams were used.

**Evaluation of the forage species biomass production**

The species were cultivated in the Agrostology Field of the UFPI/CPCE. The experimental area had 143 m² divided into 16 plots with 5 m² each, separated by 1m-wide uncultivated spaces. Twenty seeds were sown per linear metre. The fertilisation was performed according to the soil analysis as seen in Table 1 following the recommendations of Barcellos et al. (2007). The quantities applied were: 70 kg of urea ha⁻¹, 40 kg of single superphosphate ha⁻¹ and 60 kg of potassium chloride ha⁻¹. All forage crops were classified as belonging to the group ‘demanding’, receiving the same amount of fertiliser (Barcellos et al. 2007).

**Table 1. Soil chemical analysis of the area where the four forage species were planted.**

| pH     | mg dm⁻³ | cmol dm⁻¹ | % |
|--------|---------|-----------|----|
|        | P       | K         | Ca | Mg | Al | H + Al | SB  | CEC-t | CEC-T | V | m |
| 5.78   | 29.6    | 84.0      | 2.8 | 1.2 | 0.1 | 3.3    | 4.3 | 4.3   | 7.5   | 56.0 | 2.3 |

*P in water: 1:2.5 ratio.

P-K-Na: Mehlich 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: aluminium saturation index; P: Phosphorus; K: Potassium.
Harvest time varied from one species to another. The corn was harvested with 115 days, millet and sunflower with 105 days and sesame with 154 days. Corn, millet and sunflower’s harvests were carried out when their grains reached the farinaceous stage, and the sesame’s harvest was carried out when its grains were in the milky grain stage.

In the useful area, the plants were cut manually with a 12-inch stainless steel machete with a polypropylene handle (Tramontina–266191223) and weighed on a digital precision scale (Sf–4003) to obtain the green mass. Then they were taken to the forced ventilation oven at 55 °C, where they remained for 72 h obtaining the dry weight, then the production of dry forage biomass was obtained in t ha⁻¹.

**Fermentation quality and silages losses**

To evaluate pH, ammoniacal nitrogen (N–NH₃), gas losses, effluent losses, dry matter recovery and chemical composition of the silages, 16 experimental silos were made using buckets of approximately three kilograms, which were sealed with Bunsen valves adapted to its covers to allow the gases from the fermentation to escape. At the bottom of each bucket, 1 kg of sand was deposited, separated from the forage by a layer of cotton fabric, making it possible to measure the amount of effluent retained according to the methodology of Jobim et al. (2011). An amount corresponding to the density of 600 kg m⁻³ was placed in each silo to obtain a good compaction of the ensiled mass. The silos were opened after 30 days and the upper and lower layers (approximately 10 cm) of the silage were discarded for greater sampling reliability. The core silo material was removed and placed in a plastic bag for homogenisation. Then, 500 g samples were taken from each experimental unit for analysis.

In order to analyse the pH, silage samples were collected after the storage period of 30 days after silo closure, then, 100 g of fresh silage were weighed in a cup and 60 mL of water were added and allowed to rest for 30 min, after this, pH was measured using a pH metre (MA522 model, Marconi Laboratory Equipment, Piracicaba, Brazil) according to Mizubuti et al. (2009). The sample (100 g) was ground with a 1 mm mesh sieve (Method 967.03-AOAC, 1990) then stored and sealed in disposable 250ml plastic round pots for food with cap (Prafesta®, Mairiporá-SP).

Laboratory analysis of dry matter (DM, method n°. 934.01), crude protein (CP) according to the Kjeldahl method (method 981.10), ashes (Ash; method 942.05-AOAC 1990), and ether extract (EE; method 920.29-AOAC 1990) were performed. To determine the content of neutral detergent fibre (NDF) it was used the methodology of Van Soest et al. (1991) and acid detergent fibre (ADF) was determined as described by
Van Soest and Robertson (1981), with the modifications proposed in the Ankon device manual (Ankon Technology Corporation, Macedon, NY). Non-fibrous carbohydrates (NFC) were determined with the following equation of Mertens (1997): \( \text{NFC} = 100 - (\text{CP} + \text{NDF} + \text{Ash} + \text{EE}) \). The ADF residue was subsequently analysed for lignin by the solubilisation of cellulose with sulphuric acid according to AOAC (2002). Hemicellulose was calculated by the difference between cellulose with sulphuric acid according to AOAC (1990).

The animals were cannulated in the rumen with permanent fistulas. They were kept in individual stalls and submitted to a 14-day adaptation period, during which, individual feeding was provided with concentrate and corn silage in a concentrate:roughage ratio of 40:60 twice a day, the diet was formulated according to the National Research Council (2007) to meet the requirement of an ovine with live weight of ±45 kg. Water was available ad libitum. The samples of corn, millet, sunflower and sesame silages were placed in TNT-type bags (weft of 100 mm, 15 × 8 cm) in an amount of approximately 2 g DM bag⁻¹, corresponding to approximately 20 mg DM cm⁻² of the bag surface area (Nocek 1988). Incubation periods of 0, 6, 12, 24, 48, 72 and 96 h were adopted. The bags were placed in reverse order and triplicates for simultaneous removal and to promote a uniform washing of the material after removal from the rumen. After each incubation period, the bags were removed from the rumen, washed thoroughly with running and distilled water, and then dried. DM determination was performed in a forced ventilation oven at 65 °C for 72 h based on AOAC recommendations (Method 967.03; AOAC 1990).

The in-situ degradability of DM, CP and NDF was determined using the weight difference for each component between weighing performed before and after ruminal incubation and it was expressed as a percentage. After obtaining the coefficients \( A \), \( B \) and \( c \), they were inserted into the equation proposed by Ørskov and McDonald (1979) to calculate the degradability:

\[
\text{DF} = A + B \times (1 - e^{-ct})
\]

where \( \text{DF} \) = degraded fraction at time \( t \) (g kg⁻¹); \( A \) = soluble fraction (g kg⁻¹); \( B \) = potentially degradable insoluble fraction (g kg⁻¹); \( c \) = degradation rate of fraction \( B \) (h⁻¹) and \( t \) = time (h). The nonlinear parameters \( A \), \( B \) and \( c \) were estimated using iterative Gauss-Newton procedures. After determination of the parameters of the model, effective degradability (ED) of the DM, CP and NDF in the rumen were calculated using the following model:

\[
\text{ED} = A + (B \times c/c + k)
\]

\( k \) corresponds to the estimated passage rate of the particles in the rumen, which were adopted: 2, 5 and 8, simulating low, medium and high passage rates, respectively.

**Statistical design**

The results were statistically evaluated by analysis of variance using the Tukey’s test with a 0.05 probability level using the SISVAR software (Ferreira, 2011). The experimental design for the data of pH, N-NH₃, losses (gases and effluents), DM recovery and chemical composition of the silages was completely randomised with four treatments, which were the types of silages (corn, millet, sunflower and sesame silages) and four replicates \( (n = 16) \).

The degradability data were analysed by analysis of variance. The experimental design was in split-plots subdivided over time, where the silages represented the main plots and the incubation times (0, 6, 12, 24, 48, 72 and 96 h) represented the subplots. The degradation curves of DM, CP and NDF of the silages were adjusted by the respective models, which resulted in the estimates of the parameters analysed. The fraction means were compared by analysis of variance with the Tukey’s test at a level of 5% of probability using the software SISVAR® 5.6 (2011).

**Results**

**Production, fermentation quality and silages losses**

Millet presented higher production of dry forage biomass \( (p = .0121) \), followed by sesame. Corn and sunflower had lower production and sesame yielded 2.7 t ha⁻¹ more than corn.

Millet silage presented higher losses \( (p < .0001) \) by effluents (Table 3), because at the time of cutting the plant had a high moisture content, which was not observed in corn, sunflower and sesame silages (Table 2).

Sunflower silage presented higher amount of losses through gases and sesame and millet silages presented the smaller amounts \( (p = .0256; \text{Table 3}) \).
matter recovery ranged from 70.0% to 96.5% for sesame and corn silage, respectively. The sunflower silage presented the highest pH value (4.95), whereas the other silages presented similar value. Sesame and millet silages presented the highest N-NH₃ contents, while corn and sunflower silages had the lowest values.

**Chemical composition of the silages**

The dry matter contents in the silages ranged from 280.0 to 429.4 g kg⁻¹ (p < .0002), with no difference between millet, sunflower and sesame silages (Table 4). Sunflower silage presented the highest content of ash (121.0 g kg⁻¹) and differed from corn, millet and sesame silages (p < .0001) which presented values of 53.1, 52.5 and 44.7 g kg⁻¹, respectively.

Corn and millet silages presented higher amounts of NDF (p < .0001) and ADF (p < .0001) when compared to sesame and sunflower silages (Table 4). Regarding the CP, there was a range from 59.2 g kg⁻¹ for corn silage to 152.6 g kg⁻¹ for sunflower silage (p < .0001). Ether extract content was higher in sunflower and sesame silages (p < .0001). The studied silages did not differ for NFC (p = .0942).

Lignin content varied from 25.5 to 67.6 g kg⁻¹ among the silages (p < .0001). However, corn and sesame silages did not differ for this variable (Table 4). Millet and sesame silages presented the highest concentrations of cellulose (p = .0006). Corn and millet silages presented the highest levels of hemicellulose (p < .0001). The total digestible nutrients content ranged from 413.9 to 613.4 g kg⁻¹ of the DM among silages, with focus on the sunflower and sesame silages, that had the highest concentrations for this variable (p < .0001).

**In-situ degradability**

The corn silage presented the highest amount of soluble fraction of DM (p < .0001) and the millet silage presented the lowest with 258.2 and 185.9 g kg⁻¹, respectively (Table 4). The potentially degradable insoluble fraction contents of DM differed among the silages (p = .0117), especially the millet and sesame silages that presented 814.0 and 711.5 g kg⁻¹, respectively. As for the ruminal degradation rate of DM, the sunflower silage presented superiority to the other silages (p = .0588). The highest ED of DM in the passage rates of 2, 5 and 8% were for corn and sesame silages.

There was no significative difference between the silages for the soluble fraction of CP (p = .2083; Table 5). However, for potentially degradable insoluble fraction of CP the corn silage obtained the highest content, 711.6 g kg⁻¹ (p = .0017). The sesame silage presented the lowest content of fraction B, 443.3 g kg⁻¹. As for the fraction c of the CP, sunflower

| Nutrients (g kg⁻¹ DM) | Species          |
|----------------------|------------------|
| Dry matter           | Corn             |
| 404.5                | 175.4            |
| 196.5                | 251.7            |
| Ashes                | Millet           |
| 57.5                 | 79.8             |
| 79.0                 | 60.8             |
| NDF                  | Sunflower        |
| 699.9                | 738.4            |
| 441.7                | 562.4            |
| ADF                  | Sesame           |
| 341.7                | 439.0            |
| 347.7                | 369.9            |
| Crude protein        |                   |
| 66.7                 | 91.5             |
| 167.2                | 117.7            |
| Ether extract        |                   |
| 16.5                 | 15.0             |
| 146.1                | 105.4            |
| NFC                  |                   |
| 159.2                | 75.0             |
| 123.8                | 153.5            |
| Lignin               |                   |
| 27.6                 | 59.0             |
| 42.0                 | 31.4             |
| Cellulose            |                   |
| 314.1                | 380.0            |
| 305.7                | 338.5            |
| Hemicellulose        |                   |
| 358.2                | 299.4            |
| 94.0                 | 192.5            |
| TDN                  |                   |
| 459.0                | 429.6            |
| 656.3                | 564.1            |

NDF: neutral detergent fibre (g kg⁻¹ of DM); ADF: acid detergent fibre (g kg⁻¹ of DM); NFC: non-fibrous carbohydrates (g kg⁻¹ of DM); TDN: total digestible nutrients (g kg⁻¹ of DM of DM).

Table 4. Chemical composition of the sesame silage compared to the usual silages in the formulation of the treatments and in the degradability trial.

| Nutrients (g kg⁻¹ DM) | Sesame       | Millet       | Sunflower    | SEM          | p Value |
|----------------------|--------------|--------------|--------------|--------------|---------|
| Dry matter           | 429.4        | 280.7        | 280.0        | 326.5        | 1.48    | .0002  |
| Ashes                | 52.5         | 52.5         | 121.0        | 44.7         | 0.50    | <.0001 |
| NDF                  | 732.6        | 759.1        | 407.9        | 627.4        | 1.63    | <.0001 |
| ADF                  | 349.5        | 452.9        | 301.1        | 374.4        | 1.20    | <.0001 |
| Crude protein        | 59.2         | 78.8         | 152.6        | 101.3        | 0.34    | <.0001 |
| Ether extract        | 18.3         | 18.2         | 160.4        | 130.3        | 0.83    | <.0001 |
| NFC                  | 136.4        | 91.3         | 109.9        | 96.1         | 1.19    | .0942  |
| Cellulose            | 322.3        | 385.3        | 258.7        | 348.9        | 1.37    | <.0001 |
| Hemicellulose        | 383.1        | 306.2        | 196.8        | 253.0        | 1.70    | <.0001 |
| TDN                  | 434.1        | 413.9        | 613.4        | 514.4        | 1.25    | <.0001 |

*Means followed by the same letters do not differ by Tukey’s test (p < .05).
NDF: neutral detergent fibre (g kg⁻¹ of DM); ADF: acid detergent fibre (g kg⁻¹ of DM); NFC: non-fibrous carbohydrates (g kg⁻¹ of DM); TDN: total digestible nutrients (g kg⁻¹ of DM of DM); SEM: mean standard error.

Table 3. Mean values of dry forage biomass production (DFBP) and losses, dry matter recovery (DMR), pH and N-ammoniacal (N-NH₃) of the silages.

| Variables            | Silages          |
|----------------------|------------------|
| DFBP (t ha⁻¹)        | Corn             |
| 7.9                  | 17.8             |
| 7.5                  | 10.8             |
| Gases (%)            | Millet           |
| 4.3                  | 3.0              |
| 6.2                  | 3.1              |
| 0.06                 | 0.0256           |
| Efficient (%)        | Sunflower        |
| 2.8                  | 20.6             |
| 9.0                  | 9.5              |
| 1.18                 | <.0001           |
| DMR (%)              | Sesame           |
| 96.5                 | 64.6             |
| 79.8                 | 70.0             |
| 0.77                 | <.0001           |
| pH                   |                   |
| 4.21                 | 4.10             |
| 4.95                 | 4.07             |
| 0.08                 | 0.0023           |
| N-NH₃ (%)            |                   |
| 5.88                 | 7.64a            |
| 5.33                 | 8.85             |
| 0.56                 | .0061            |

*aMeans followed by the same letters do not differ by Tukey’s test (p < .05); bN-NH₃ is expressed based on total nitrogen. SME: mean standard error.
and sesame silages presented values higher than millet and corn silages \((p = .0042)\). For the ED of CP with a passage rate of 2% the silages presented significative difference \((p = .0009)\). However, ED 5% of CP ranged from 388.6 to 443.6 \(g \text{ kg}^{-1}\) among the silages \((p = .0008)\). While regarding the ED 8% of CP, the sesame silage was superior to the other silages \((p = .0021)\). Soluble fraction \((p = .0622)\), potentially degradable insoluble fraction \((p = .3726)\), degradation rate \((p = .4547)\) and ED in the passage rates of 5% \((p = .8631)\) and 8% \((p = .8587)\) of the NDF did not differ among the studied silages (Table 5). However, ED 2% presented the lowest content in millet silage \((p = .0046)\).

**Discussion**

### Influence of silage chemical composition on fermentative indicators and losses

The highest value for losses through gases in sunflower silage may have occurred due to the undesirable fermentations caused by gas-producing microorganisms such as enterobacteria and clostridial bacteria (Edvan et al. 2013), a fact that may not have occurred in sesame and millet silages as they presented lower losses.

Silage effluents are also a source of losses and that occur more often in silages that have high moisture content (Rego et al. 2012), and in situations where it is not possible to reach the required DM. Nevertheless, the corn silage presented lower losses by effluents because the plant had already reached an advanced maturation stage and presented at the time of ensiling 404.50 \(g \text{ kg}^{-1}\) of DM. At the time of ensiling, sesame presented 251.70 \(g \text{ kg}^{-1}\) of DM, a value considered adequate by some authors (Mota et al. 2011).

Regarding the recovery of dry matter, corn silage obtained the highest efficiency presenting lower loss of dry matter, followed by sesame and sunflower silages, and that is related to the lower losses (gases and effluents). However, millet silage presented the lowest DM recovery.

The sunflower silage presented a pH of 4.95, higher than the other silages, and this may have been due to the DM content that makes compaction difficult, allowing a higher presence of air, favouring the colonisation of aerobic bacteria and impairing the fermentation. However, the quality aspects such as colour and odour were satisfactory during the opening of the silos. Pinho et al. (2013), reported that pH values between 3.8 and 4.2 are considered adequate for well-preserved silages, since in this range there is a restriction of proteolytic enzymes of the plant, enterobacteria and clostridium. Thus, corn, millet and sesame silages that did not present significative differences are within the recommended range.

### Table 5. Rumen degradation of dry matter, crude protein and neutral detergent fibre of sesame silage compared to the usual silages, incubated in the rumen.

| Variables \((g \text{ kg}^{-1})\) | Corn | Millet | Sunflower | Sesame | SEM | \(p\) Value |
|---|---|---|---|---|---|---|
| **Dry matter \((g \text{ kg}^{-1})\)** | | | | | | |
| A \(258.2^a\) | 185.9\(^{bc}\) | 218.4\(^b\) | 214.7\(^b\) | 0.36 | <.0001 |
| B \(680.9^{ab}\) | 814.0\(^a\) | 489.2\(^b\) | 711.5\(^a\) | 4.48 | .0117 |
| c \((\% \text{ h}^{-1})\) \(0.0121^{ab}\) | \(0.0083^{b}\) | 0.0158\(^b\) | 0.0114\(^{ab}\) | 0.001 | .0588 |
| ED2 \(533.3^{b}\) | 398.0\(^b\) | 320.6\(^b\) | 302.6\(^b\) | 0.0121 | .0042 |
| ED5 \(346.6^{b}\) | 265.0\(^b\) | 333.3\(^b\) | 307.3\(^b\) | 0.0083 | .0001 |
| **Crude protein \((g \text{ kg}^{-1})\)** | | | | | | |
| A \(263.6^a\) | 278.8\(^a\) | 242.7\(^a\) | 271.7\(^a\) | 1.09 | .2083 |
| B \(711.6^{ab}\) | 671.8\(^a\) | 557.1\(^{bc}\) | 443.3\(^a\) | 2.73 | .0017 |
| c \((\% \text{ h}^{-1})\) \(0.0090^{b}\) | \(0.0100^{b}\) | 0.0270\(^a\) | 0.0320\(^b\) | 0.003 | .0042 |
| ED2 \(533.3^{b}\) | 388.8\(^a\) | 434.6\(^a\) | 437.3\(^a\) | 0.0270 | .0008 |
| ED5 \(403.6^{b}\) | 352.0\(^c\) | 381.3\(^a\) | 423.9\(^a\) | 0.0270 | .0021 |
| **Neutral detergent fibre \((g \text{ kg}^{-1})\)** | | | | | | |
| A \(45.7^a\) | 59.3\(^a\) | 51.4\(^a\) | 69.1\(^a\) | 0.49 | .0622 |
| B \(437.8^a\) | 415.8\(^a\) | 452.5\(^a\) | 528.3\(^a\) | 4.37 | .3726 |
| c \((\% \text{ h}^{-1})\) \(0.0266^{b}\) | \(0.0300^{a}\) | 0.0233\(^a\) | 0.0200\(^a\) | 0.004 | .4547 |
| ED2 \(296.6^{ab}\) | 302.0\(^b\) | 306.3\(^b\) | 306.3\(^b\) | 0.24 | .0046 |
| ED5 \(199.0^{b}\) | 201.6\(^b\) | 202.3\(^b\) | 202.3\(^b\) | 0.49 | .8631 |
| ED8 \(156.0^{b}\) | 158.3\(^b\) | 159.0\(^a\) | 162.3\(^a\) | 0.52 | .8587 |

\*Means followed by the same letters do not differ by Tukey’s test \((p > .05)\).

A: soluble fraction \((g \text{ kg}^{-1})\); B: potentially degradable insoluble fraction \((g \text{ kg}^{-1})\); c: degradation rate of fraction B \((\% \text{ h}^{-1})\); ED2 \((g \text{ kg}^{-1})\): effective degradability with passage rate of 2% per hour; ED5 \((g \text{ kg}^{-1})\): effective degradability with passage rate of 5% per hour; ED8 \((g \text{ kg}^{-1})\): effective degradability with passage rate of 8% per hour; SEM: mean standard error.
Regarding the concentration of N-NH$_3$, sesame and millet silages had higher contents. However, among the forage species studied, all of them presented adequate levels, ranging from 53.3 to 88.5 g kg$^{-1}$, as contents higher than 100 g kg$^{-1}$ are indicative of intense proteolysis and undesired fermentations that should be avoided in silage making (Pacheco et al. 2015).

Sesame, sunflower and millet silages showed higher dry matter contents in relation to the forage before ensiling. This fact may have occurred due to high losses by effluents (Ribeiro et al. 2010). The highest ashes content was observed in sunflower silage. However, this may be due to the high content of silica or inorganic contaminants (sand) that would not be used by the animals (Possenti et al. 2005).

The higher contents of NDF and ADF in corn and millet silages may be related to the phenological stage of the plant that at the time of ensiling. This represents a negative aspect for animal nutrition, since the high concentration of NDF in the diets has been identified as one of the main regulators of consumption due to its slow degradation and reduced passage rate (Arcari et al. 2016). However, low values were observed only in sunflower silage. Regarding the high contents of ADF, several factors contributed, among them the high amount of dead material and stem or stalk. The lower contents of ADF in the silages of sunflower, sesame and corn show improvements in the quality of the silages, since the fibre is composed of cellulose and lignin.

Corn and sesame silages showed lower values of lignin and cellulose, which may increase the digestibility of these silages. Thus, the lignin content is considered the main factor of the plant involved in reducing the digestibility of the forages (Pholsen et al. 2016). Another positive point of the corn and sesame silages was the low hemicellulose content, because when the forage has a high content of hemicellulose, its fibrous components of the cell wall are high, making it difficult to consume and digest the feed (Silva et al. 2015). The non-fibrous carbohydrate (NFC) contents of the studied silages were considered low, however that did not compromise the quality of the silages produced.

Regarding CP and EE, higher values were observed in sunflower and sesame silages. This is because tropical grasses silages present low content of these nutrients, which is a limitation to their exclusive use, especially for animals of high nutritional requirement (Melo et al. 2016). Sunflower and sesame silages presented higher amounts of total digestible nutrients; however, this fact is directly related to the NDF levels that were lower in these silages, positively influencing the energy levels of the feed.

**Forage species production and degradability of silage chemical compounds**

The higher production of dry forage biomass presented by millet is due to its adaptability to tropical regions, as well as sesame, and that was not observed for corn and sunflower, which had lower yields. Despite the higher production, millet obtained low recovery of dry matter (DMR), resulting in less silage produced. A forage species to be ensiled must have high biomass production, adaptability to the region, adequate chemical characteristics and low loss of dry matter of the ensiled biomass (Rezende et al. 2011). In tropical regions it is important to have alternative to corn cultivation for silage production (Daniel et al. 2019).

The highest levels of fraction A in DM were observed in corn silage. This was probably due to a better quality of NFC. Thus, more digestible forages present high values of soluble fraction.

The potentially degradable insoluble fraction B of DM was higher in millet and sesame silages, probably because they presented lower values of fraction A, especially when compared to corn silage. Regarding the degradation rate c of DM, corn, sunflower and sesame silages presented higher rates, indicating that these materials require less time inside the rumen to reach their maximum degradation potential (Tagawa et al. 2017). Corn and sesame silages obtained higher values of ED of DM at passage rates of 2, 5 and 8% per hour. These results suggest a better nutritive value of these silages when compared to the other silages evaluated (Silva et al. 2014).

The soluble fraction of CP was similar in the studied silages. This result shows that the protein fraction of the silages is slowly available to the animal (Miyaji et al. 2017). However, the lower concentrations of fraction A may be related to high values of fraction B.

Regarding the potentially degradable fractions B of CP, the sesame silage presented the lowest concentration. However, the content of the degradable fraction was always higher compared to the soluble fraction, due to the higher solubility of CP (Geraseev et al. 2011).

The contents of the fraction A of NDF were different from the presented for the fraction B of NDF, since the NDF fractions of the silages may present high solubility in water. Effective degradability for the silages at passage rates of 2, 5 and 8% per hour can...
be considered good when compared to silages from other crops (Ferreira et al. 2016). Thus, lower concentrations of effective degradability of NDF is an indicative that the plant should be ensiled younger.

The dry matter degradability at time zero (0 h) was around 22% for all silages. However, as the time passed the degradability increased faster until 48 h, when it was observed the inflection point of the degradation curve tending to stabilise after 72 h. The maximum degradation potential of DM of all silages was obtained with 96 h. Corn and sesame silages showed higher disappearance of the DM, which may have occurred due to the greater potential degradation in these silages when compared to millet and sunflower silages. After 96 h of ruminal incubation, the DM degradation values observed were high (above 600 g kg\(^{-1}\)), however, the stabilisation of the degradability of the silages was not observed, showing that the silages still had degradation potential after 96 hours. Pires et al. (2010) observed values for DM degradability in corn and sorghum silages similar to the ones in the present study (74.4 and 754.0 g kg\(^{-1}\)).

For the crude protein degradability, significative differences were not verified between the silages until 6 h of incubation. However, from that moment on, sunflower and sesame silages stood out in relation to corn and millet silages. Even though, the sesame silage was superior to the sunflower silage until 24 h, from that moment on, the sunflower silage showed greater disappearance of CP. Thus, the maximum CP degradability potential of the silages was obtained with 96 hours of incubation. However, it was observed that sunflower and sesame silages presented stabilisation with 72 h, but it was not observed stabilisation of CP disappearance in corn and millet silages, showing that they still had degradability potential after 96 hours.

NDF degradability in the studied silages at time zero (0 h) was considered to be 0%, since the constituents of the cell wall, the fibrous fraction of the feed, are insoluble in water, therefore, there are no significative losses of NDF at the time 0 h, as the bags are only washed in running water (Jobim et al. 2011).

After 6 h of incubation, the degradation of the NDF increased up to 48 h, where the inflection point of the curve was found for all silages. Sesame silage presented higher degradation of NDF than the other silages until 48 h of incubation, from that point on it remained higher without reaching the disappearance stabilisation, obtaining the highest degradation potential of NDF (519.9 g kg\(^{-1}\)) at the time 96 h when compared to corn, millet and sunflower silages. That shows that the sesame silage still had degradability potential after 96 hours. On the other hand, it was observed that corn, millet and sunflower silages showed stabilisation at 72 h and obtained maximum disappearance potential (450.0 g kg\(^{-1}\)) at 96 h.

**Conclusions**

The sesame presents high biomass production and chemical characteristics suitable to ensiling, and its silage shows quality similar to corn and millet regarding the nutritional value, being a good alternative for regions of tropical climate.

The results of this study demonstrate the forage use of sesame for silage production, however, field studies need to be carried out to evaluate the performance of animals consuming sesame silage, as well as to evaluate its effect on animal health.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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