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Corn Silage as a Total Diet with by-Products of the Babassu Agroindustry in the Feed of Confined Ruminants

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Abstract: This study aimed to evaluate the chemical composition of total ration silage (TRS) containing two babassu by-products to replace the corn. The silages were formulated to meet the requirements of sheep for an average daily gain of 200 g/day. A completely randomized experimental design was used with four treatments and five replications. The treatments consisted of CS: Corn silage (Control); TRSS: Corn silage with corn and soybean meal; TRSF: Total ration silage with babassu mesocarp flour; and TRSC: Total feed silage with babassu cake. The chemical composition of the silages had a significant difference ($p < 0.05$) for all variates. There was a significant difference ($p < 0.001$) for gas (LG, $p < 0.001$) and effluent losses (LE, $p < 0.001$), dry matter recovery (DMR, $p < 0.001$), buffer capacity (BC, $p < 0.001$), lactic acid (LA, $p < 0.001$), butyric acid (BA, $p < 0.001$), lactic acid/fermentation products (LA:FP, $p < 0.001$), and ammoniacal nitrogen (NH_3-N, $p < 0.001$). The babassu by-products can replace ground corn by up to 50% in total ration silage and improve the fermentation profile and nutritional value of the silage, meeting the nutritional requirements of finishing sheep.

Keywords: *Attalea speciosa*; fermentation profile; losses

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1. Introduction

The advance in animal production requires a high demand for concentrated products, such as corn and soybeans, which causes competition for these products between humans and animals. In this way, the use of by-products from agroindustry and family farming has become an alternative to replace these ingredients partially or totally in animal feed. The available amount of these materials is abundant and usually negatively impacts the environment. Thus, the optimization of their use has been the subject of several research studies because if 5% of the by-products are used correctly in animal feed, it would be enough to meet the demands of the existing herds in the world [1].

The by-products of the babassu palm (*Attalea speciosa* Mart. ex Spreng), such as mesocarp flour and cake, are residues from the extraction of the oil contained in the fruit kernels during the industrialization process [2,3]. Both are promising options to replace ground corn, the main energy concentrate used in animal feed. Furthermore, according to Zanine et al. [4], the average production of babassu fruits is 2400 kg/ha, as 1780 kg (74%) is related to the Endocarp/Epicarp; 480 kg (20%) to the mesocarp; and 140 kg (6%) to the almonds, in addition to having 52% starch.

In this way, using babassu by-products in animal feed to replace other energy concentrates would reduce the environmental impacts generated by the disposal of these products in nature. However, these by-products are unstable, and the process of oxidative rancidity is rapid, which is when the lipids are degraded, reducing product quality and shelf life [3]. Therefore, it is recommended that these by-products be preserved with other ingredients in the form of total ration silage (TRS).

TRS is a technology that has been standing out due to the wide variety of feeds that can be used in its production, such as fresh forages, forages with high moisture contents, wet or dry concentrates, and agroindustry by-products [5]. This technique can be applied in any region of the world since the ingredients used can be found in local industries, which reduces the costs of animal feed and labor on the farm.

In this way, the production of TRS based on babassu by-products and the corn plant becomes a promising alternative because it is expected that the inclusion of these by-products in the silage will provide well-fermented silages with high hygienic quality. It can become a promising alternative for finishing small ruminants in confinement because it minimizes production costs and reduces the environmental impacts generated by the local agroindustry. Thus, the use of babassu by-products improves the fermentative and bromatological characteristics of total ration silage (TRS) in addition to being able to replace corn grain by 50% to meet the requirements of sheep.

In this way, this research aimed to evaluate the chemical composition of TRS containing two babassu by-products that replace ground corn to meet the requirements of sheep for an average daily gain of 200 g/day.

2. Materials and Methods

2.1. Experimental Location

The research was carried out at the Centre for Agricultural and Environmental Sciences of the Federal University of Maranhão (UFMA) in the town of Chapadinha, Maranhão, located at latitude 3°43′57.8″ south and longitude 43°19′07.3″ west. The climate classification of the region according to Köppen is type Aw with the rains being distributed in the months of November to March and an average annual precipitation of 1670 mm/year.

2.2. Treatments and Experimental Design Adopted

Table 1 shows the chemical composition values of the babassu by-products used in the experiment.

Table 1. Chemical composition of babassu by-products.

Item, %DM	Babassu Flour	Babassu Cake
Dry matter	87.4	89.0
Ash	3.1	4.1
Crude protein	5.1	15.5
Ether extract	2.2	12.0
Neutral detergent fiber corrected for ash and protein	66.0	63.5
Acid detergent fiber corrected for ash and protein	54.7	53.7
Hemicellulose	11.2	9.8
Cellulose	37.9	43.3
Acid detergent lignin	16.8	10.3
Total carbohydrates	89.6	68.4
Non-fiber carbohydrate	1.3	4.9

The total ration silages were composed of 50% roughage, corn silage, and 50% concentrate (Table 2); the concentrates were composed of soybean meal, ground corn, urea, mineralized salt, babassu cake, and babassu mesocarp, replacing 50% of the ground corn in the standard silage as energy sources.

Table 2. Chemical composition of diets at the time of ensiling.

Item, g/kg DM	Silages			
	CS [1]	TRSS [2]	TRSF [3]	TRSC [4]
Ground corn	0.0	340	170	170
Soybean meal	0.0	139	139	145
Babassu cake	0.0	0.0	0.0	170
Babassu flour	0.0	0.0	170	0.0
Urea	0.0	6.0	6.0	0.0
Mineral salt	0.0	15.0	15.0	15.0
Corn silage	1000	500	500	500
Chemical Composition				
Dry matter	207.30	361.20	349.50	386.90
Ash	42.40	58.90	56.60	61.20
Organic matter	957.60	940.90	943.30	938.70
Crude protein	74.20	137.00	115.00	128.80
Ether extract	27.70	25.00	25.60	24.90
Neutral detergent fiber	656.60	597.50	543.60	524.30
Acid detergent fiber	485.90	334.10	377.10	376.60
Hemicellulose	170.70	263.40	166.50	147.70
Water-soluble carbohydrates	116.80	105.10	96.40	98.40

[1] CS: Corn silage (Control); [2] TRSS: Corn silage with corn and soybean meal; [3] TRSF: Total feed silage with babassu mesocarp flour replacing 50% of the ground corn; [4] TRSC: Total feed silage with babassu cake replacing 50% of the ground corn.

The experimental design used was completely randomized with four treatments and five replications. The treatments consisted of CS: Corn silage (Control); TRSS: Corn silage with corn and soybean meal; TRSF: Total feed silage with babassu mesocarp flour replacing 50% of the ground corn; and TRSC: Total feed silage with babassu cake replacing 50% of the ground corn (Table 2).

The experimental diets in the form of SRT were formulated to meet the nutritional requirements of sheep with an average weight of 20 kg and average daily gain of 200 g/day according to NRC [6].

2.3. Silage Making

The corn plant used in the present study is the off-season type intended for grain production, causing the dry matter (DM) content of the plant to be below the recommended amount for silage production at the time of harvesting the ear (30 to 35% MS) (Table 2). The plant was cut approximately 10 cm from the soil and chopped in a silage machine coupled to a tractor with a particle size of 2 cm. Then, the ingredients were mixed manually. At this moment, samples of the in natura mixture were collected to evaluate the chemical composition of the diets.

The silage was carried out in experimental polyvinyl chloride (PVC) silos with a capacity of 3.6 L (length: 191.4 mm, height: 156.5 mm, and width: 193.6 mm). After mixing, the material was compacted until reaching an approximate density of 550 kg/m^3 based on the fresh matter.

To ensure that the gases resulting from the fermentation of the ensiled material were eliminated, all the experimental silos were fitted with a Bunsen valve. A total of 1 kg of dry sand was added to the bottom of each experimental silo, which was covered with non-woven fabric (TNT), to quantify the losses by the effluents. All the experimental silos were closed, weighed, and stored at room temperature in a ventilated, dry, and covered place.

2.4. Fermentative Profile

After 45 days of ensiling, all the experimental silos were weighed and opened. The silages were manually removed and homogenized from each experimental silo. Samples were collected when the silos were opened and stored for later analysis of the fermentative profile and chemical composition.

The pH values of the evaluated silages were quantified following the methodology proposed by Bolsen et al. [7]. In each treatment, samples of 25 g were analyzed, and 100 mL of distilled water was added; the readings were taken after 1 h of rest.

Ammoniacal nitrogen content ($N\text{-}NH_3/TN$, in %) was determined according to the methodology described by Nogueira and Souza [8]. The organic acids (lactic acid, acetic acid, propionic acid, and butyric acid) were determined with high-performance liquid-phase chromatography (HPLC) according to Kung Jr. and Ranjit [9]. The fermentation products were calculated as the sum of lactic acid, other volatile fatty acids, ethanol, acetic acid, butyric acid, and propionic acid [10].

The buffering capacity (BC) was analyzed according to Playne and McDonald [11]. For this, approximately 15 g of the macerated sample was used together with 250 mL of distilled water using a potentiometer.

The dry matter losses in the silages as effluents and gases were quantified by the weight difference using the equations described by Zanine et al. [12].

The dry matter content and gas and effluent losses were quantified by the weight changes using the equations described by Zanine et al. [12]:

$$GL = (WFp - WFo)/(FOMc \times DMp) \times 1000$$

where GL = gas losses (% of dry matter), WFp = weight of the filled silo at closing (kg), WFo = weight of the filled silo at opening (kg), FOMc = forage mass at silo closing (kg), and DMc = dry matter content at silo closing (%).

$$EL = [(WEf - Tb) - (WEp - Tb)]/FOMc \times 100$$

where EL = effluent losses (kg ton^{-1} fresh matter), WEp = weight of the empty silo + sand at closing (kg), WEf = weight of the empty silo + sand at opening (kg), Tb = weight of the empty silo (kg), and FOMc = forage mass at silo closing (kg).

Dry matter recovery was estimated based on the difference in the dry matter mass before and after ensiling using the equation described by Zanine et al. [12]:

$$DMR = (FOMo \times DMo)/(FOMc \times DMc) \times 100$$

where DMR = dry matter recovery rate (%), FOMo = forage mass at silo opening (kg), DMo = forage dry matter content at silo opening (%), FOMc = forage mass at silo closing (kg), and DMc = dry matter content at silo closing (%).

2.5. Chemical Composition Analysis

Samples of the material were collected before ensiling and after opening the experimental silos for further analysis of the chemical composition. These samples were pre-dried in a forced ventilation oven at 55 °C for 72 h. Then, they were ground in a Wiley knife mill with a sieve size of 1 mm and stored in plastic jars with lids, labeled, and subjected to analyses to determine the dry matter (DM; method 934.01), ash (method 930.05), crude protein (CP; method 920.87), and ether extract (EE; method 920.39) contents [13]. The analyses for the determination of neutral detergent fiber (NDF) and acid detergent fiber (ADF) were done according to Van Soest et al. [14].

To obtain the ash and protein-corrected neutral detergent fiber (NDFap) content, the neutral and acid detergent digestion residues were corrected for ashes and protein by incineration in a muffle oven at 600 °C for 4 h, and the protein correction was based on neutral detergent insoluble protein (NDIP) and acid detergent insoluble protein (ADIP) according to Licitra et al. [15]. The acid detergent lignin (ADL) content was determined using the method 973.18 (AOAC, 2012) [13]. The other cell wall fractions were determined using the following equations: hemicellulose = NDF − ADF and cellulose = ADF − ADL.

Total carbohydrates (TC) were quantified using the equation proposed by Sniffen et al. [16]. The equation NFC = 100 − (%CP + %NDFap + EE + Ash) was used to estimate non-fiber carbohydrate (NFC) contents, as proposed by Detmann et al. [17]. To estimate the levels of soluble carbohydrates present in the samples, we followed the methodology proposed by Dubois et al. [18]. Total digestible nutrients (TDN) were estimated according to Van Soest (1994), and in vitro dry matter digestibility (IVDMD) was estimated according to the methodology proposed by Tilley and Terry [19].

2.6. Aerobic Stability

The silage samples were placed without compaction in experimental PVC silos without a lid and kept in a closed environment with a controlled temperature (25 °C). Aerobic stability was determined as the time required to raise the silage temperature by 2 °C above ambient temperature after exposure to air [20]. The silages were exposed to air for a period of 120 h. The silage temperatures were measured every minute using encapsulated temperature sensors (DS18B20—Maxim Integrated™, DS18B20, California, United States, operating temperature range −55 to 125 °C, accuracy ± 0.5 °C) that were interconnected to a microcontroller (Atmega2560—Arduino®, Mega 2560, Italy). The sensors were inserted into the center of the silo's mass at a depth of 15 cm.

2.7. Statistical Analysis

The experiment was conducted in a completely randomized design with four treatments and five replicates per treatment. The following statistical model was used:

$$Y_{ik} = \mu + S_i + \varepsilon_{ik}$$

Y_{ik} is a measurement-dependent variable in the experimental unit 'k' of the experience silage 'i';

μ is the general constant;

S_i is the effect of silages and

ε_{ik} is the random error effect.

The command PROC GLM in SAS 9.1® software was used. The data were submitted for analysis of variance, and the means were compared with the Tukey's test. *p* values less than 0.05 were considered significant.

3. Results

There was no difference for the pH (p = 0.236) and water-soluble carbohydrates (WSC) (p = 0.269) in the evaluated silages, presenting averages of 3.94 and 92.1 g/kg DM, respectively. For the buffer capacity, there was a significant difference (p < 0.001) with the highest value presented in the CS. No difference was observed among the TRS (Table 3).

Table 3. Fermentative characteristics and organic acid contents (%DM) of total ration silages with babassu by-products.

Item	Silages				SEM	*p*-Value
	CS [1]	TRSS [2]	TRSF [3]	TRSC [4]		
pH	3.92	3.98	3.96	3.92	0.502	0.236
Water-soluble carbohydrates (g/kg DM)	100.5	94.8	90.1	83.0	0.316	0.269
Buffer capacity (E. mgNaOH)	0.06 [a]	0.04 [b]	0.04 [b]	0.04 [b]	0.003	<0.001
Lactic acid (g/kg DM)	55.15 [b]	62.25 [a]	62.01 [a]	63.08 [a]	0.125	<0.001
Acetic acid (g/kg DM)	11.54	12.33	12.87	12.97	0.245	0.299

Table 3. *Cont.*

Item	Silages				SEM	*p*-Value
	CS [1]	TRSS [2]	TRSF [3]	TRSC [4]		
Butyric acid (g/kg DM)	13.82 [a]	11.32 [b]	11.44 [b]	11.53 [b]	0.047	<0.001
Propionic acid (g/kg DM)	0.44	0.56	0.51	0.61	0.427	0.178
Ethanol (g/kg DM)	13.95	12.47	12.84	13.61	0.147	0.259
LA:FP (%) [5]	58.11 [b]	62.98 [a]	62.29 [a]	63.14 [a]	0.002	<0.001
NH_3-N (% N total)	4.77 [b]	8.14 [a]	5.20 [b]	5.22 [b]	0.358	<0.001

[1] CS: Corn silage (Control); [2] TRSS: Corn silage with corn and soybean meal; [3] TRSF: Total feed silage with babassu mesocarp flour replacing 50% of the ground corn; [4] TRSC: Total feed silage with babassu cake replacing 50% of the ground corn. [5] LA:FP = percentage of lactic acid in the fermentation products (FP = lactic acid + acetic acid + butyric acid + ethanol) − percentage of lactic acid as the end product of fermentation. SEM: standard error of the mean. Means followed by different letters on the lines differ with Tukey's test at 5% probability.

There was a significant difference among the treatments for the variables of lactic acid (LA, $p < 0.001$) and butyric acid (BA, $p < 0.001$). The CS showed a lower mean for LA and a higher mean for BA. However, there was no significant difference for acetic acid (AA, $p = 0.299$) and propionic acid (PA, $p = 0.178$) with general averages of 12.42 and 0.53 g/kg DM, respectively (Table 3).

There was no difference ($p = 0.259$) for the ethanol contents of the silages with a general average of 13.21 g/kg DM. However, there was a significant difference for the N-NH_3 ($p < 0.001$) and LA/FP ($p < 0.001$) variables among the silages evaluated. The highest N-NH_3 value was observed for the TRSS. The lowest percentage of lactic acid in the fermentation products (LA/FP) was observed in the corn silage (Table 3).

There was a significant difference for gas losses (GL, $p < 0.001$), effluent losses (EL, $p < 0.001$), and dry matter recovery (DMR, $p < 0.001$) during the ensiling process. The CS showed higher means for GL and EL. However, the DMR was lower in the CS. (Table 4).

Table 4. Losses and dry matter recovery during the fermentation process of total ration silages with babassu by-products.

Item	Silages				SEM	*p*-Value
	CS [1]	TRSS [2]	TRSF [3]	TRSC [4]		
Gas losses (%DM)	0.10 [a]	0.05 [b]	0.05 [b]	0.04 [b]	0.007	<0.001
Effluent losses (kg/ton.)	0.40 [a]	0.04 [b]	0.03 [b]	0.03 [b]	0.038	<0.001
Dry matter recovery (%DM)	86.93 [b]	90.20 [b a]	97.18 [a]	93.06 [a]	1.482	<0.001

[1] CS: Corn silage (Control); [2] TRSS: Corn silage with corn and soybean meal; [3] TRSF: Total feed silage with babassu mesocarp flour replacing 50% of the ground corn; [4] TRSC: Total feed silage with babassu cake replacing 50% of the ground corn. SEM: standard error of the mean. Means followed by different letters on the lines differ with Tukey's test at 5% probability.

For aerobic stability ($p = 0.829$) and hours/maximum temperature ($p = 0.965$), no significant differences ($p > 0.05$) were observed among the studied silages, presenting averages of 85.89 and 102.61 h, respectively. However, there was a significant difference ($p = 0.027$) for the max temperature (°C) in 120 h of evaluation with the highest mean being observed in the CS and the lowest in the TRSF (Table 5).

The chemical composition of the silages is shown in Table 6. Higher values of ash ($p = 0.002$), neutral detergent fiber (NDF, $p < 0.001$), and total carbohydrates (TC, $p < 0.001$) were observed for the CS in relation to the TRS. However, for dry matter (DM, $p = 0.002$), organic matter (OM, $p < 0.001$), crude protein (CP, $p < 0.001$), total digestible nutrients (TDN, $p < 0.001$), and in vitro digestibility of DM (IVDMD, $p = 0.001$), the lowest values were observed for the CS in relation to the TRS (Table 6).

Table 5. Values of maximum temperature and aerobic stability in total ration silages with babassu by-products.

Item	Silages				SEM	p-Value
	CS [1]	TRSS [2]	TRSF [3]	TRSC [4]		
Aerobic stability (hours)	89.88	79.98	87.37	86.35	3.62	0.829
Max temperature in 120 h (°C)	30.38 [a]	29.63 [ab]	27.88 [b]	28.63 [ab]	0.34	<0.027
Hours/ Max temperature	101.66	100.46	104	104.35	2.84	0.965

[1] CS: Corn silage (Control); [2] TRSS: Corn silage with corn and soybean meal; [3] TRSF: Total feed silage with babassu mesocarp flour replacing 50% of the ground corn; [4] TRSC: Total feed silage with babassu cake replacing 50% of the ground corn. SEM: standard error of the mean. Means followed by different letters on the lines differ with Tukey's test at 5% probability.

Table 6. Chemical composition and in vitro dry matter digestibility of total ration silages with babassu by-products.

Item (g/kg DM)	Treatments				SEM	p-Value
	CS [1]	TRSS [2]	TRSF [3]	TRSC [4]		
Dry matter	192.5 [b]	344.4 [a]	347.9 [a]	328.8 [a]	1.52	<0.001
Ash	55.9 [a]	37.9 [c]	42.7 [bc]	52.4 [bc]	0.22	0.002
Organic matter	944 [c]	962 [a]	957 [ab]	947.6 [bc]	0.22	<0.001
Crude protein	80.3 [c]	139.9 [b]	145.8 [b]	161.5 [a]	0.72	<0.001
Ether extract	26.9 [a]	25.6 [ab]	15.8 [c]	23.8 [b]	0.13	<0.001
Neutral detergent fiber corrected for ash and protein	659 [a]	409.9 [c]	482.3 [bc]	500.4 [b]	2.26	<0.001
Acid detergent fiber corrected for ash and protein	445.2 [a]	197 [d]	260.5 [c]	362.3 [b]	22.3	<0.001
Cellulose	350.8 [a]	257.4 [bc]	239.1 [c]	305.8 [ab]	1.16	<0.0001
Hemicellulose	213.8	212.9	221.8	138.1	0.80	0.329
Acid detergent lignin	94.4 [a]	27.0 [b]	70.2 [a]	43.9 [b]	0.65	<0.001
Total carbohydrates	834 [a]	796.2 [b]	796.7 [b]	765.2 [c]	0.66	<0.001
Non-fiber carbohydrate	174.9 [c]	381.8 [a]	305.8 [ab]	242.3 [bc]	2.18	<0.001
Total digestible nutrients	743.5 [c]	881.7 [a]	828.2 [b]	814.4 [b]	1.30	<0.001
In vitro digestibility of DM	589.70 [b]	693.02 [a]	686.45 [a]	687.74 [a]	5.69	0.001

[1] CS: Corn silage (Control); [2] TRSS: Corn silage with corn and soybean meal; [3] TRSF: Total feed silage with babassu mesocarp flour replacing 50% of the ground corn; [4] TRSC: Total feed silage with babassu cake replacing 50% of the ground corn. SEM: standard error of the mean. Means followed by different letters on the lines differ with Tukey's test at 5% probability.

4. Discussion

The silages presented pH values within the recommended range (>3.80 and <4.20) by McDonald et al. [21] for well-fermented silages. Bautista et al. [22] found similar values for pH (3.9) working with corn silage and the addition of 10% molasses. On the other hand, total ration silage (TRS) is characterized by having a less intense fermentation and pH values above 4.20, as observed by Yang et al. [23] in their respective research evaluating TRS. In the present study, this was not observed because the WSC levels present in the corn plant at the time of ensiling were converted to organic acids, mainly LA, which was responsible for reducing the pH of the ensiled mass [20]. In this way, it can be said that the WSC present in the corn plant was sufficient to guarantee the fermentation process of the ensiled mass, maintaining its nutritional and hygienic quality.

The highest values of LA were found in the TRS, which can be explained by the WSC content and the increase in the mixture DM that was consequently reduced in the water activity of the ensiled mass by the addition of concentrated ingredients, including babassu by-products, especially when compared with the CS. Thus, the DM content of the mixture at the time of ensiling influenced its fermentation process (Table 3) by lactic acid bacteria [24,25]. This way, it can be affirmed that the DM levels of the off-season corn plant (<25%) at the time of silage had a negative influence on the LA levels from the CS treatment, which justifies the results obtained for the losses of gas and effluent from the CS.

Dry matter contents below 25% lead to a greater development of bacteria of the clostridium genus responsible for producing butyric acid, which negatively influences the development of the bacteria of the LAB genus responsible for adequate conservation of silage [21]. Furthermore, deleterious microorganisms need water activity above 0.6 for development and reproduction. Thus, AW expressed on a scale from 0 to 1 is a determining factor for the development of microorganisms involved in the fermentation processes of silage [26].

The addition of concentrates increased the interaction between the LA and fermentation profile among the total ration silages when compared to the corn silage. This result can be attributed to greater water activity in the corn silage and the action of microorganisms, which resulted in the highest losses by gases and effluents. The increase in the DM influenced the fermentation of the silages by the LAB, producing LA, and other microorganisms, such as ethanol-producing yeasts, since these microorganisms require moisture activity for growth and reproduction [24,25]. The BC values in the present study were below the minimum value of 25 mg HCL/100 g MS suggested by McDonald [21].

The silages showed N-NH_3 values below 10% without showing differences among the treatments with the inclusion of babassu by-products. This result indicates the quality of fermentation; according to McDonald et al. [21], levels above 10% are indicators of unwanted fermentation and intense proteolysis in the silage fermentation process. According to AFRC [27] and Henderson [28], values of N-NH_3 considered the ideal for excellent quality silage should reach a maximum of 8 to 11%. According to McDonald et al. [21], when the pH decreases slowly, protein degradation is expected, reducing crude protein levels and increasing N-NH_3 levels. However, when the total ration silages presented low levels of BC, there was a faster reduction in pH, and this degradation was inhibited. The levels of ammoniacal nitrogen in a silage is a parameter of great importance, as it indicates the loss of protein, which is an essential nutrient in the diet of ruminants, and indicates a greater intensity of proteolysis, mainly due to the degradation of amino acids by proteolytic clostridia. Excessive ammonia nitrogen values (above 10%) cause low animal acceptability and, consequently, poor animal performance.

GL and EL were higher in the CS compared to the total ration silages; this can be explained by the greater activity of gas-producing microorganisms, such as enterobacteria, clostridial bacteria, and yeasts [21]. For the total ration silages, no differences were observed. The result evidences the moisture-absorption action of the babassu by-products. Rezende et al. [29], working with sugarcane silages, reported a reduction of up to 40% in the losses of gas and effluent. These losses are related to the fermentation profile of the silages; however, the highest losses are caused by heterofermentative bacteria [30]. A decrease in gas production, which can result from a reduction in the action of gas-producing microorganisms such as *Enterobacteriaceae* and *Clostridium* bacteria, can result in poorly fermented silages.

For BA values, the highest value was attributed to the corn silage (CS) due to the lower NDF and NFC contents in the corn silage at the time of silage. According to McDonald et al. [21], dry matter values below 25% result in a greater development of bacteria of the *clostridium* genus, which produce butyric acid.

The BA of the silages is above those recommended as ideal (below 0.1%) according to Mahanna [31] and Roth and Undersander [32]. However, the other parameters evaluated (losses and pH) do not indicate secondary fermentation among the total ration silages. The CS showed a lower DM recovery, probably due to greater loss by effluents, in relation to the other treatments. However, no differences were observed among the total ration silages, which indicates a higher quality of fermentation of the silages [33]. Zanine et al. [4], working with babassu by-products, found similar results to the present study.

The addition of concentrates in the total ration silages balanced the water-soluble carbohydrate content, which showed an adequate supply of carbohydrates from the babassu by-products such as sucrose and fructose. These components are the main sources of carbohydrates for microbial development throughout the fermentation period of silages [34].

The corn silage showed a lower value of DM (192.5 g/kg) in relation to the other treatments that presented values between 344.4 and 328.8 (g/kg), thus explaining the hydroscopic effect of the ingredients included in the other treatments, which may also be explained by the maturation stage of the corn plant used (milky). Oliveira [35] observed values of 23.6 g/kg dry matter of corn silage in the milky and pasty stages, a result similar to the present study.

Gusmão et al. [36], working with total ration silage and using elephant grass as a forage source, observed that the diet with only grass stood out with lower dry matter values, similar to the present study.

For the crude protein content, the corn silage showed means (80.3 g/k) within the standards for corn silage (80 g/k) [37]. The silage with the babassu cake inclusion in its composition was superior to the others in relation to crude protein content, which can be explained by the higher crude protein content of the babassu cake. The higher ash content of the total ration silage can be related to the higher levels of minerals present in the babassu by-products, the cake, and mesocarp flour.

The CS showed higher NDFap, ADFap, and CEL contents compared to the TRS, which resulted in an increase in the NFC concentration of the total ration silages, improving the energy availability for ruminant animals. However, the TRSC silage presented a higher average of NDFap (500.4 g/kgM) in relation to the TRSS silages, a fact that is explained based on the higher NDF content of the babassu cake. Santos et al. [3], working with these by-products, found 64.40% NDF for babassu flour, and Rostagno et al. [38] found 37.10% NDF for babassu mesocarp flour. The differences in the NDF content may be associated with the type of processing and the differences in the climate and region of the samples that were used since these variables can change the chemical composition of this ingredient.

According to Van Soest [39], it is interesting that silages with lower NDF values present a direct relationship with the DM intake by the animals. Mertens [37] observed that lower ADF values characterize a silage of better quality because it is a structural component with an inverse relation to dry matter digestibility. Lower CEL and LIG values are also important in silage as these structural components are less digestible, whereas cellulose is partially digestible, and the lignin is indigestible.

For the variable ether extract, the corn silage showed a higher average (26.9 g/kg) than the other treatments that received the babassu by-products TRSF (15.8) and TRSC (23.8) (g/kg), respectively, but there was no difference between the treatment that was formulated based on the standard diet using corn and soybean. These events are attributed to the chemical composition of the diets based on the formulation. Valadares Filho et al. [40], working with babassu cake, found ether extract values between 5.51 and 4.23%.

The TRSC showed the lowest content of total carbohydrates possibly due to higher contents of crude protein, ether extract, and mineral matter of the ingredients used in the total ration silage. As for the higher NFC content observed among the treatments, this could possibly be attributed to the lower NDFap content. This result provided higher averages of TDN. Cabral et al. [41], evaluating corn silages as a function of their grain content, observed that an increase in the NFC content through the grains increased the TDN levels. This way, it can be said that the inclusion of concentrates improved the nutritional levels of these silages.

The corn silage showed the lowest in vitro digestibility of DM, which can be explained by the lower TDN content and the higher lignin content present in this silage. In the other silages, an increase was observed in relation to the corn silage attributed to the concentrate used, evidencing the quality of the babassu by-products in the total ration silage. The results obtained for the maximum temperature variable may be associated with the dry matter contents of the silages because it needs to produce more heat to change the silage temperatures with lower dry matter contents [21,42].

The loss of aerobic stability of the silages evaluated in the present study starts at 89.88 h; according to Pitt [43], this result can be attributed to different factors, such as the concentration of CO_2 and O_2, forage moisture, ambient temperature, as well as soluble carbohydrates and concentration of organic acids.

Evaluating the results of this research, the TMR ensiling technique is a promising alternative to correct the DM of the corn plant at the time of ensiling when adverse reasons, such as pests and an early harvest due to a decrease in rainfall in the region among others, can affect plant and grain development. In addition to optimizing the use of agro-industrial residues found in the region, it improves the fermentative profile of harvested maize plants with DM less than 35%.

5. Conclusions

The babassu by-products can replace ground corn by up to 50% in total ration silage, improve the fermentation profile and nutritional value of silage, and meet the nutritional requirements of finishing sheep.

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