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Effects of Adding Agro-Industrial By-Products of Babassu to Guinea Grass Silage

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Abstract: Using by-products added to grass silage in the total mixed ration (TMR) silage form can bring advantages to the ensiling process, raising DM levels, absorbing moisture, and improving the silage's chemical composition. The aim of this study was to evaluate the effect of babassu by-products' inclusion substitution for corn in Guinea grass silage in the total mixed ration as an alternative feed for ruminants. The experiment was a completely randomized design with four treatments (silage) and five replications (silo). There was a significant difference in the fermentation profile and losses of silage ($p < 0.001$), some organic acids (lactic and butyric acids, $p < 0.001$), and the percentage of lactic acid in fermentation products (LA:FP, $p < 0.001$). The TGS showed the highest average for the variable's maximum temperature ($p < 0.001$) and hours/max temperature ($p = 0.011$). Babassu by-products could eventually replace 50% of corn in total mixed rations silage containing Guinea grass, meeting the suggestion for the total mixed ration silage.

Keywords: *Attalea especiosa*; chemical composition; fermentation profile

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1. Introduction

The world demand for animal protein production is 58%, with an exponential increase expected until the year 2050 [1,2], and sheep farming is a promising culture with estimates of an increase in meat production according to data from the Centro de Goat and Sheep Market and Intelligence (CIM). However, for this, it is necessary to use feeding techniques that promote production rates, such as alternative feeds and feed preservation techniques, including silage.

Among the principal grasses used in animal feed, Guinea grass (*Megathyrsus maximus*) stands out, which is widespread and used among producers, and is thus able to take advantage of its forage surplus during the rainy season to carry out ensilage and enhance the feeding of livestock in the dry season [3–5]. However, grass silages are hard to conserve due to high moisture and low water-soluble carbohydrate content. This leads to high losses and inadequate fermentation profiles. To combat these issues, by-products can be added to reduce leaching, improve fermentation, increase dry matter and soluble carbohydrates, and lower pH and N-ammonia levels [6].

In this sense, in total mixed ration (TMR) silages, the ingredients are mixed inside a silo, combining forages, protein and energy concentrates, vitamins, minerals, additives, and by-products. This combination of ingredients has a positive effect on the fermentation profile, which reduces undesirable fermentations and improves the quality of ensiling [7–10].

Animal feed can benefit from various by-products, including babassu by-products (starch flour and cake) that can be added to grass silage [11] in the form of TMR silage and which bring benefits to the ensiling process, including raising DM levels, absorbing moisture, and improving the silage chemical composition. By adding babassu cake and meal to silage, the protein content increases, meeting animals' nutritional needs. The fiber present in these by-products improves digestibility and promotes better nutrient utilization by animals. In addition, the use of babassu by-products reduces food waste and avoids disposal [6].

Given this, this study aimed to assess the use of babassu by-products, such as mesocarp flour and babassu cake, as a substitute for corn in Guinea grass silages in the total ration for ruminants.

2. Materials and Methods

2.1. Location and Origin of the Babassu by-Product

The experiment took place at the Centre for Agricultural and Environmental Sciences of the Federal University of Maranhão (UFMA) in Chapadinha, Maranhão (3°43′57.8″ S 43°19′07.3″ W). This region has a hot tropical Aw climate [12] with a rainy season from November to March and an average annual rainfall of 1670 mm.

2.2. Treatments and Experimental Design

Fifty percent of the corn in the total mixed ration (TMR) silages was replaced with babassu cake and starchy flour (Granulometry Type I) by-products. The company Florestas Brasileiras S.A., based in Itapecuru Mirim—MA—Brazil, provided the babassu by-products. The table in Table 1 shows the chemical composition of by-products from babassu and Guinea grass (*Megathyrsus maximus*).

Table 1. Chemical composition of Guinea grass and babassu by-products.

Item, %DM	Guinea Grass	Babassu Flour	Babassu Cake
Dry matter	22.6	87.0	89.0
Ash	8.52	3.8	4.1
Crude protein	6.82	5.21	16.0
NDFap [1]	73.32	65.0	63.5
Acid detergent fiber	64.20	54.7	53.7
Hemicellulose	9.12	11.2	9.78
Cellulose	58.5	38.0	43.0
Acid detergent lignin	5.72	17.0	10.0
Ether extract	2.33	2.20	12.0
Total carbohydrates	82.33	89.6	68.4
Non-fiber carbohydrate	9.01	23.6	4.90

[1] NDFap: Neutral detergent fiber corrected for ash and protein.

Four treatments were evaluated: 100% Guinea grass silage (TGS-control) and three total mixed rations silages. The silages contained a concentrate roughage ratio of 50:50 for Guinea grass silage with corn and soybean meal (TMRS-standard diet), Guinea grass silage with corn, soybean meal, and babassu flour (TMRF), and Guinea grass silage with corn, soybean meal, and babassu cake (TMRC).

Twenty experimental silos were used in a completely randomized design, with four treatments and five replications each. The silos contained the total mixed ration silages consisting of 50% Guinea grass silage and 50% concentrate (Table 2), which were formulated to meet the nutritional requirements of sheep weighing an average of 20 kg with an average daily gain of 200 g/d, and an estimated average DM intake of 0.60 kg/day (3% PC) according to NRC [13].

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

Item, g/kg DM	Silages			
	TGS [1]	TMRS [2]	TMRF [3]	TMRC [4]
Ingredients				
Guinea grass silage	1000	500	500	500
Corn meal	0	300	150	150
Soybean meal	0	135	135	135
Molasses	0	50	50	50
Babassu cake	0	0	0	150
Babassu flour	0	0	150	0
Urea	0	2	4	0
Mineral mixture [1]	0	12	12	12
Chemical composition				
Dry matter	226	545	547	546
Ash	85.2	74.7	77.1	77.5
Crude protein	68.2	128	128	133
NDFap [5]	733	436	514	511
Acid detergent fiber	642	349	425	423
Hemicellulose	91.2	86.9	88.7	87.95
Cellulose	585	320	371	380
Acid detergent lignin	57.2	28.6	54.1	43.6
Ether extract	23.3	44.6	37.3	52.0
Total carbohydrates	823	753	757	737
Non-fiber carbohydrate	90.1	317	244	226
Water-soluble carbohydrates	8.77	11.8	10.7	10.6
Metabolizable energy (Mcal/day)	1.34	2.09	1.90	1.90

[1] TGS: Guinea grass silage (control); [2] TMRS: Guinea grass silage with corn and soybean meal (standard diet); [3] TMRF: Guinea grass silage with corn, soybean meal and babassu flour; [4] TMRC: Guinea grass silage with corn, soybean meal and babassu cake. [5] NDFap: Neutral detergent fiber corrected for ash and protein.

2.3. Preparation of Diets and Ensiling

Guinea grass was cut to 10 cm above ground, chopped in a forage machine, and manually mixed with other ingredients (ground corn, soybean meal, babassu flour, or babassu cake). A sample was collected after mixing to evaluate the chemical composition of the diets at the time of ensiling. The results are shown in Table 2.

Polyethylene silos with a 3.6 L capacity (191.4 mm L × 156.5 mm H × 193.6 mm W) were used for ensiling the material. They were equipped with a Bunsen valve to release gases. In each silo, a piece of fabric was used to separate 1 kg of dehydrated sand from the forage material to prevent contamination and improve drainage. Posteriorly, the sand was gathered and weighed to analyze the effluents, as per Jobim et al. [14]. The material in the silos was compacted to a density of 550 kg/m^3 for maximum oxygen removal. Then, the silos were weighed, sealed with a plastic lid, and wrapped with adhesive tape.

2.4. Fermentative Profile

After fermenting for 45 days, the silos were weighed and opened, and the resultant silage was manually removed, homogenized, and a sample was taken for the fermentative profile and chemical composition.

To analyze the pH, 25 g of the sample was mixed with 100 mL of distilled water and left to rest for an hour before measuring the pH using a potentiometer [15].

The ammoniacal nitrogen content (NH_3-N) was measured using 15 g of fresh silage and 100 mL of potassium chloride solution (15%), which were then processed in a blender for 5 min, after which 10 mL was filtered and collected for analysis. This material was added to a digester tube along with 250 mg of calcined magnesium oxide, which was distilled to capture the ammonia [16].

To determine the buffering power (BP), a 15 g sample macerated with 250 mL of distilled water was used. Using a potentiometer, bicarbonates, such as CO_2, were released by titrating the material to pH 3.0 using 0.1 N HCl. Then, the material was titrated to pH 6.0 with 0.1 N NaOH, and the volume of NaOH used to change the pH from 4.0 to 6.0 was recorded, as described by Playne and McDonald [17].

In total, 25 g of the sample was blended with 225 mL of distilled water for 1 min and then filtered using filter paper to evaluate the organic acids. In Becker, 10 mL of the diluted sample, two drops of concentrated sulfuric acid, 5 mL of metaphosphoric acid, and 1 mL of metaphosphoric acid for each 2 mL of silage were homogenized and acidified in a vortex using test tubes. Then, they were centrifuged for 10 min at 15,000 rpm, and the supernatant was collected. The supernatants were analyzed using high-performance liquid phase chromatography (HPLC, model SPD-10a VP, Dallas, Texas, United States of America) with an Ultraviolet Detector (UV) at a wavelength of 210 nm column: C18 (Reverse Phase); Brand: SUPELCO; measurement: 30 cm × 4.5 mm in diameter; column flow: 0.6 mL/minute; column pressure: 87 Kgf; mobile phase: water in 1% sulfuric acid and injected volume: 10 ul according to Siegfried et al. [18].

Gas and effluent losses in silage were quantified by weight difference using the equations according to Jobim et al. [14] and adapted by Zanine et al. [19]:

$$GL = [(WSf - WSo)]/[(FMf \times DMf)] \times 100 \quad (1)$$

where *GL* = gas loss during storage (% of initial DM); *WSf* = the weight of the silo in the silage; *WSo* = the weight of the silo in the opening; *FMf* = forage mass in the silage; *DMf* = forage DM content in the silage.

$$E = (Wop - Wen)/(Gmef) \times 1000 \quad (2)$$

where *E* = effluent production (kg/t of green mass); *Wop* = set weight (silo + sand + cloth + mesh) in the opening (kg); *Wen* = set weight (silo + sand + cloth + mesh) in the silage (kg); *GMef* = green mass of ensiled forage (kg).

The dry matter recovery (*DMR*) index was estimated using the following equation:

$$DMR = (FMop \times DMop)/(FMcl \times DMcl) \times 100 \quad (3)$$

where *FMop* = the forage mass at opening; *Dmop* = the MS content at opening; *FMcl* = the forage mass at closing; *DMcl* = the DM content of forage at closure.

2.5. Chemical Composition

The chemical composition analyses of ingredients and silages were conducted at the Laboratory of Products of Animal Origin (LAPOA-UFMA-BRAZIL) and the Laboratory of Food Analysis and Animal Nutrition (LAANA-UFPB-BRAZIL).

To assess the chemical composition, samples were collected from the ingredients, including fresh material pre-ensiling and the post-opening of silos. Before analysis, the samples were dried for 72 h at 60 ± 5 °C in a forced ventilation oven and ground in a Willey knife mill with a 1 mm sieve. The dry matter (DM, method 934.01), crude protein (CP, Kjeldahl method 920.87), ether extract (EE, method 920.39), and ash (method 930.05) contents were analyzed according to AOAC [20] with organic matter (*OM*) calculated by the equation:

$$OM\ (\%) = 100 - \%Ash \quad (4)$$

The neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Van Soest et al. [21]. Neutral detergent insoluble nitrogen (NDIN) and acid detergent insoluble nitrogen (ADIN) values were obtained using the recommendations of Licitra et al. [22]. The Neutral detergent fiber corrected for ash and protein (NDFap) was calculated by subtracting CIDN and NDIN from the NDF percentage after incinerating the NDF residue at 600 °C for 4 h. The acid detergent lignin (ADL) contents were determined by treating the ADF residue with 72% sulfuric acid [23]. The hemicellulose content was calculated by subtracting ADF from NDFap, while cellulose content was calculated by subtracting lignin from ADF.

The total carbohydrate (*TC*) was calculated using the equation provided by Sniffen et al. [24]:

$$TC = 100 - (\%CP + \%Ash + \%EE) \quad (5)$$

The non-fiber carbohydrate (*NFC*) was calculated using the equation by Detmann et al. [25]:

$$NFC = 100 - (\%CP + \%NDFap + \%EE + \%Ash) \quad (6)$$

Soluble carbohydrates were quantified using the concentrated sulfuric acid method described by Dubois et al. [26]. The equation from Harlan et al. [27] was used to measure the total digestible nutrients (*TDN*):

$$TDN = 82.75 - (0.704 \times ADF) \quad (7)$$

In vitro DM digestibility was determined following Tilley and Terry [28]. *TDN* was converted to metabolizable energy (ME) using NRC's equation: [23]

$$Digestible\ energy\ (DE) = \left(\frac{TDN}{100}\right) \times 4.409 \quad (8)$$

$$Metabolizable\ energy = DE \times 0.82 \quad (9)$$

2.6. Aerobic Stability

The aerobic stability test evaluated silage by monitoring internal temperature during air exposure. The silage samples were placed in PVC silos without compaction or lids and were stored in a controlled environment at 25 °C. Silage temperatures were monitored using DS18B20 temperature sensors (models DS18B20, Maxim Integrated™, DS18B20, San Jose, CA, USA, operating temperature range −55 to 125 °C, accuracy ±0.5 °C), which were inserted 10 cm into the center of the mass and connected to an ATmega2560 microcontroller (Arduino®, Mega 2560, Ivrea, Italy) programmed to record the temperature per minute for six days.

The ambient temperature was also controlled and measured using sensors suspended in the room. The loss of aerobic stability was determined by checking if the temperature of the ensiled material after opening exceeded 2 °C at an ambient temperature [29].

2.7. Statistical Analysis

The experiment used a completely randomized design with four treatments and five replicates per treatment and employed the following statistical model:

$$Yik = \mu + Si + \varepsilon ik \quad (10)$$

where:

Yik is a measurement-dependent variable in the experimental unit '*k*' of the experience silage '*i*';
μ is the general constant;
Si is the effect of silage;
εik is the random error effect.

The study utilized the PROC GLM command in SAS 9.1® [30] software for data analysis. The mean comparison was performed using Tukey's test and significance was considered for *p*-values less than 0.05.

3. Results

Table 3 presents data on fermentation profiles, losses, and organic acid values in total ration silages containing babassu by-products. There were significant differences in the pH ($p < 0.001$), NH_3-N ($p < 0.001$), gas losses (GL, $p < 0.001$), effluent losses (EL, $p < 0.001$), dry matter recovery (DMR, $p < 0.001$), and water-soluble carbohydrates (WSC $p < 0.001$). However, buffering capacity (BC) showed no statistical difference ($p = 0.234$).

Table 3. Fermentation profile, losses, and organic acid content of babassu by-product total ration silages.

Item	Silages				SEM	*p*-Value
	TGS [1]	TMRS [2]	TMRF [3]	TMRC [4]		
pH	5.15 b	4.99 c	5.16 b	5.34 a	0.03	<0.001
Buffer capacity (E. mg NaOH)	0.81	0.71	0.78	0.80	0.02	0.234
NH_3-N (%N total)	11.19 a	7.30 c	6.74 c	8.94 b	0.41	<0.001
Gas losses (%DM)	0.214 a	0.102 b	0.105 b	0.110 b	0.01	<0.001
Effluent losses (kg/ton)	23.89 a	14.72 b	13.30 b	13.05 b	1.21	<0.001
Dry matter recovery (%DM)	85.93 b	97.01 a	96.67 a	96.88 a	1.29	<0.001
Water-soluble carbohydrates (g/kg DM)	55.4 b	90.9 a	82.0 a	80.2 a	0.38	<0.001
Lactic acid (g/kg DM)	40.15 b	52.25 a	52.01 a	53.08 a	0.37	<0.001
Acetic acid (g/kg DM)	2.8	3.28	3.3	3.32	0.02	0.243
Butyric acid (g/kg DM)	2.62 a	2.19 b	2.13 b	2.22 b	0.01	<0.001
Propionic acid (g/kg DM)	1.2	1.31	1.28	1.44	0.36	0.124
Ethanol (g/kg DM)	14.3	12.37	12.71	13.31	0.26	0.148
LA:FP (%) [5]	61.07 b	71.40 a	71.43 a	73.37 a	0.01	<0.001

[1] TGS: Guinea grass silage (control); [2] TMRS: Guinea grass silage with corn and soybean meal (standard diet); [3] TMRF: Guinea grass silage with corn, soybean meal, and babassu flour; [4] TMRC: Guinea grass silage with corn, soybean meal, and babassu cake, [5] LA:FP = percentage of lactic acid (LA) in relation to FP (fermentation products = lactic acid + acetic acid + butyric acid + propionic acid + ethanol). SEM: standard error of the mean. Means followed by different letters on the lines differ by Tukey's test at the 5% level of significance.

There was a significant difference in pH values ($p < 0.001$), with TMRC silage having the highest average and TMRS silage having the lowest. However, there was no significant difference in buffer capacity ($p = 0.234$) with an average of 0.78 E. mg NaOH.

A significant difference was observed for N-NH_3 ($p < 0.001$), in which lower values were observed in TMRS and TMRF silages, while the highest value was for TGS. TMR silages showed higher dry matter recovery (DMR, $p < 0.001$) compared to TGS, whereas higher gas losses (GL, $p < 0.001$) and effluent losses ($p < 0.001$) were observed for TGS compared to TMR silages. TMR silages had significantly higher averages for water-soluble carbohydrates (WSC, $p = 0.001$) than TGS.

Significant effects were observed for lactic acid (LA, $p < 0.001$), butyric acid (AB, $p < 0.001$), and the percentage of lactic acid in relation to fermentation products (LA:PF, $p < 0.001$). No significant differences were found for acetic acid (AA) ($p = 0.2425$), propionic acid (PA) ($p = 0.1235$), and ethanol ($p = 0.1478$).

The chemical composition for in vitro dry matter digestibility and nutrient values of silages are presented in Table 4. TMR silages had higher means of DM ($p < 0.001$), CP ($p < 0.001$), and TDN ($p = 0.003$) compared to TGS, while TGS had higher values of NDFap ($p < 0.001$), ADFp ($p < 0.001$), and TC ($p < 0.001$).

Table 4. Chemical composition for in vitro dry matter digestibility of total ration silages with babassu by-products.

Item (g/kg DM)	Silages				SEM	*p*-Value
	TGS [1]	TMRS [2]	TMRF [3]	TMRC [4]		
Dry matter	206.30 c	310.06 a	306.03 ab	298.65 b	0.99	<0.001
Ash	105.07 a	81.58 b	84.59 b	98.67 a	0.24	<0.001
Organic matter	894.93 b	918.42 a	915.41 a	901.33 b	0.24	<0.001
Crude protein	65.53 b	125.77 a	129.58 a	130.52 a	0.62	<0.001
NDFap [5]	696.36 a	465.52 c	545.93 b	582.81 b	2.00	<0.001
Acid detergent fiber	606.43 a	414.11 c	411.60 c	461.58 b	1.83	<0.001
Acid detergent lignin	130.61 ab	120.43 b	161.28 a	140.68 ab	0.56	0.048
Hemicellulose	89.93 ab	51.41 b	134.33 a	121.24 a	0.90	<0.001
Cellulose	475.81 a	293.68 b	250.33 c	320.901 b	1.27	<0.001
Ether extract	17.45	18.65	19.22	19.35	0.08	0.847
Total carbohydrates	812.0 a	774.0 b	766.6 b	751.5 b	0.45	<0.001
Non-fiber carbohydrate	115.6 c	308.5 a	220.7 b	168.7 b	1.91	<0.001
Total digestible nutrients	594.01 b	665.69 a	632.89 a	652.80 a	1.51	0.003
In vitro digestibility of DM	522.69 b	635.39 a	623.57 a	628.07 a	14.4	0.007
Metabolizable energy (Kcal/day)	2.12 c	2.38 a	2.27 b	2.34 a	0.04	<0.001

[1] TGS: Guinea grass silage (control); [2] TMRS: Guinea grass silage with corn and soybean meal (standard diet); [3] TMRF: Guinea grass silage with corn, soybean meal, and babassu flour; [4] TMRC: Guinea grass silage with corn, soybean meal, and babassu cake, [5] NDFap: neutral detergent fiber corrected for ash and protein; ME: Metabolizable energy, SEM: standard error of the mean. Means followed by different letters on the same lines differ by Tukey's test at the 5% level of significance.

Ash ($p < 0.001$) showed a significant effect with higher means for TGS and TMRC silages. TMRS and TMRF silages showed a higher organic matter (OM, $p < 0.001$) content.

A significant difference was observed between the silages in terms of the acid detergent lignin (ADL) ($p = 0.048$), hemicellulose ($p < 0.001$), and cellulose ($p < 0.001$). TMR silages had a higher content of non-fibrous carbohydrates (NFC, $p < 0.001$), and a lower concentration was observed for the TGS. The concentration of ether extract (EE, $p = 0.847$) did not differ significantly among silages. The total digestible nutrients (TDN, $p = 0.003$), in vitro DM digestibility ($p = 0.007$), and metabolizable energy (ME, $p < 0.001$) were significantly higher in TMR silages compared to TGS.

Table 5 presents data on the aerobic stability of silages. The TGS silage showed a higher temperature than the TMR silage ($p < 0.001$). Among the TMR silages, there was no significant difference. For the hours/max temperature variable, the exclusive Guinea grass silage had the highest average, and the lowest was found for TMR silages with babassu by-products ($p = 0.011$).

Table 5. Maximum temperature and aerobic stability in dairy sheep diets after 114 h of exposure.

Item	Silages				SEM	*p*-Value
	TGS [1]	TMRS [2]	TMRF [3]	TMRC [4]		
Ambient Temperature (°C)	25.00	25.00	25.00	25.00	------	------
Aerobic stability (hours)	>114	>114	>114	>114	------	------
Max temperature in 120 h (°C)	25.50 [a]	25.12 [b]	25.00 [b]	25.00 [b]	0.06	<0.001
Hours/Max temperature	48.69 [a]	13.30 [ab]	0.00 [b]	0.00 [b]	9.51	0.011

[1] TGS: Guinea grass silage (control); [2] TMRS: Guinea grass silage with corn and soybean meal (standard diet); [3] TMRF: Guinea grass silage with corn, soybean meal, and babassu flour; [4] TMRC: Guinea grass silage with corn, soybean meal and babassu cake. Means with different letters on the lines differ from each other by Tukey's test at 5% probability.

4. Discussion

A silage pH between 3.8 and 4.2 indicates better conservation of the ensiled material, as it reduces undesirable fermentations [31]. In the present study, among the evaluated silages, the lowest pH value observed was for TMRS (4.99). The TMRC treatment had the highest average; this might have happened due to the higher protein content in this silage. Possibly, the high CP content in the silages could have interfered with the buffering capacity of the material, resulting in a slower pH drop. Therefore, CP degradation could have occurred during the ensiling process, thus releasing amino acids, peptides, and ammonia. These compounds act as weak acids, contributing to the neutralization of acids produced during fermentation. Thus, the high presence of CP may have delayed the decline in pH since the acids produced were counterbalanced by the buffering capacity provided by products of protein degradation [31].

For buffer capacity (BC), there was no difference between treatments. According to Jobim et al. [14], the buffering power is the interaction of the plant's composition with the levels of crude protein, inorganic ions (Ca, K, Na), organic acids, and their salts.

The NH_3-N (%N total) content in the TMR reduced when compared to exclusive Guinea grass silage (TGS) due to the inclusion of the concentrate that increased the DM of the diet and decreased the activity of undesirable bacteria in the fermentation of the silage. Among the TMR silages, the silage with babassu cake (TMRC) showed a higher average than TMRS and TMRF due to the CP content of this by-product. The ammoniacal nitrogen content of TMR silages was classified as good according to McDonald [31], Tomich et al. [32]; Hepered et al. [33] classified less than 10% of NH_3-N between 10 and 15% as acceptable and above 20% as unsatisfactory. This is because, according to McDonald [31] the ammoniacal nitrogen content in silages is antagonistic to the drop in pH, which shows a beneficial effect in the allocation and use of nitrogen in mass due to the proteolytic metabolism of clostridium [34].

When observing losses in silage, the inclusion of concentrates in TMR silages provided greater efficiency in reducing losses by gases (GL) and effluents (EL) compared to TGS [6,35]. The reduction was due to the increase in the DM content of the concentrate included in the diets that acted by absorbing moisture from Guinea grass silage. The babassu by-products present in TMRF and TMRC proved to be equivalent to the standard corn and soybean concentrate (TMRS), reducing losses that were related to water activity, the DM content of the ensiled forage, the physical treatment applied to the forage at the time of cutting and the use of additives, whether chemical or nutritional [35]. Additionally, linked to the reduction in gas and effluent losses, the TMR silages reached high dry matter recovery (DMR) for TGS, remaining above 90%, demonstrating that the TMR of the present study met the prerequisites of the silage process efficiently.

These results corroborate with studies by Zanine et al. [36], who evaluated the fermentative characteristics and chemical composition of TMR containing flour and babassu cake with average results of DMR above 90%, confirming the low loss of DM when the inclusion of concentrates is considered in TMR silages.

In the present study, there was a reduction in the water-soluble carbohydrates (WSC) content of the silages for the pre-ensilage material (Table 2): an effect that was already expected and crucial since the soluble carbohydrates were consumed by microorganisms, generating organic acids such as fermentation products. There was no difference between the TMR silages indicating that the contribution of soluble carbohydrates from the by-products of babassu is equivalent to the standard concentrates used in animal feed.

TMR silages had a higher lactic acid (LA) content than TGS due to the higher concentration of water-soluble carbohydrates (WSC) present in the ingredients and added to TMR silages. There was no difference among the TMR silages, indicating that the babassu by-products added to the silages showed satisfactory fermentative capacity. Regarding the acetic acid (AA) content, there was no significant difference between the silages, demonstrating that the fermentation profile of silages was controlled.

Guinea grass silage showed higher butyric acid (BA) and ammonia nitrogen (NH_3-N) contents than TMR silage. The DM content of TGS may have provided the proliferation of undesirable microorganisms, as silages with a DM content of less than 25% provide a favorable environment for the development of bacteria of the genus *Clostridium* [31], which are responsible for affecting the conservation efficiency of the silage using carbohydrates, proteins, or even the lactic acid present in silages as a substrate for its growth, thus increasing its losses, in addition to providing unfavorable sensory characteristics for animal intake, which can directly affect their performance [34,35].

All silages had concentrations of propionic acid (PA) below 5 g/kg of DM, within the recommended limit for an ensilage to be considered excellent quality [37]. It is important to point out that propionic acid, together with acetic acid, acts as an antifungal [38] and plays important roles in silages.

The percentage of lactic acid (LA) for fermentation products (FP) (LA: PF) is considered a strong indicator of the fermentative quality of the silage, and in the present study, this ratio presented a lower mean for the Guinea grass silage (TGS), indicating that the TMR silages have a predominance of lactic acid ($\geq$71% LA: FP); that is, it presented an excellent fermentation pattern [39].

When evaluating the chemical composition of the silages, the variables DM and CP presented higher values in TMR silages for the TGS, which ensued due to the addition of concentrates and babassu by-products with elevated levels of DM that acted as moisture absorbers. In addition, they contained, in their composition, higher concentrations of CP for Tanzânia grass. Gusmao et al. [10], evaluating total ration silages based on elephant grass, also observed an increase in DM and CP contents in TMR treatments about exclusive grass silage. The silages presented a DM content between the ideal values of 280 and 350 g/kg [31]. On the other hand, the crude protein contents found in the TRM silage in the present study presented values above 7%, as described by Van Soest (1994), for microbial fermentation to occur properly.

There was a reduction in the DM content of the silages compared to the pre-ensiled material; this decrease was expected during the fermentation process [31], and usually, the losses are in smaller proportions in TRM silage compared to grass silages.

The disappearance of DM in TMR silages during the fermentation process could be related to the moisture content of the Guinea grass at the time of ensiling, although the chemical composition was maintained close to the initial values.

TGS had a higher NDFap, ADF, and cellulose content due to the higher concentration of these constituents present in the grass compared to the other ingredients used in TMR silage. A lower concentration of these fiber fractions allows for greater nutrient intake and better energy availability of ruminants.

Hemicellulose is an NDF fraction that is potentially digestible with high degradation in the rumen and is often used as the principal energy source for cell wall components. The greater the speed of hemicellulose degradation, the more significant the cell wall digestibility alongside emptying the rumen, reducing physical filling, and allowing a high DM intake. The TMR silages using babassu by-products showed higher averages for this variable, which could be considered an alternative in ruminant feeding.

Total carbohydrates had a higher average for TGS, which could be related to intrinsic factors of the chemical composition of the silage, such as its high content. Thus, this silage had a lower non-fiber carbohydrate (NFC) content in its composition. There was a difference between the TMR silages: the highest concentration was observed for the TMRS silage due to the composition and nutritional quality of corn and soybean. There was no difference between treatments with the inclusion of babassu by-products.

The NFC represents the fraction rapidly degraded in the rumen, including pectin, starch, and sugars, as constituents of the cellular content and used as a source of readily available energy for ruminal microorganisms. In the ruminal environment, the fermentation of these carbohydrates generates organic acids that meet up to 80% of the daily energy requirement, potentiate the production of microbial protein, and maintain the ruminal environment [39]. However, when diets have high concentrations of CNF, they can cause an imbalance in ruminal pH, requiring synchronization between the amount of fibrous and non-fibrous carbohydrates together with sources of nitrogen available in the diet to maintain the conditions of adequate ruminal kinetics, providing greater efficiency in the development of ruminal microorganisms [40].

TMR silages showed higher TDN and ME averages when compared to TGS. The values were close to those estimated by the NRC [13] to meet the nutritional requirements of small ruminants. Demonstrating that the addition of concentrates in the total mixed ration (TMR) promoted the greater availability of nutrients, this corroborates with in vitro digestibility, indicating that babassu by-products have the potential to be used in the diet of ruminants.

As for the evaluation of aerobic stability (AS), there was no break in any of the silages evaluated during the evaluation period. There was little oscillation and an increase in the temperature of the silages, which remained stable during the hours of exposure to air. This evaluation considers the stability of the silage after opening the silo, determined by the oxidation of the ensiled mass; that is, how long after opening the silo, the ensiled mass in contact with oxygen managed to maintain a constant temperature. The loss of aerobic stability was considered when the temperature of the ensiled material exceeded 2 °C of the ambient temperature [29]; this is because the contact of silage with oxygen tends to provide opportunities for the de-sporulation of some facultative anaerobic microorganisms, and the speed of this process varies according to the moisture content, particle size and compaction of the ensiled material and silo sealing [41].

Some factors directly affect the growth of microorganisms that deteriorate the silages, such as the oxygen present in the medium, pH, temperature, water activity, and organic acids [42]. However, with the high pH value from silages, it is believed that the fermentation route may have been altered with the significant production of acetic acid.

TMR silages showed higher aerobic stability. Different ingredients added to the silage favored the fermentation process when compared to exclusive Guinea grass ensilage. The same behavior was observed by Gusmão et al. [10] when evaluating total mixed feed silage containing elephant grass.

5. Conclusions

Babassu cake and starchy flour could eventually replace 50% of corn in total rations containing Guinea grass silage, meeting the suggestion for the total mixed ration silage. Babassu by-products have been proven to be equivalent in their fermentation profile and chemical composition to standard concentrates, in addition to reducing the costs of feedlot sheep diets, depending on their availability in the region.

Regarding the CP content, there was no difference among TMR silages, with averages above 120.0 g/kg DM, which is consistent with meeting the requirements of feedlot beef sheep. Babassu by-products are efficient compared to standard concentrates, corn, and soybean, indicating a viable alternative to animal feed since protein is one of the most expensive components of the diet.

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