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Mixed Ration Silage Containing Tanzania Grass and Babassu By-Products for Dairy Cows

Daniele Ferreira [1], Danrley Bandeira [1], Anderson Zanine [1,*], Henrique Parente [1], Michelle Parente [2], Edson Santos [3], Anny Graycy Lima [1], Ricardo Pinho [4], Juliana Oliveira [3], Francisco Naysson Santos [1], Francisca Claudia Sousa [1], Renata Costa [1], Carlos Rodolfo Castro [1] and João Ricardo Dórea [5]

[1] Department of Animal Science, Federal University of Maranhão, Chapadinha 65500000, Brazil
[2] Department of Animal Science, Federal University of Piauí, Teresina 64049550, Brazil
[3] Department of Animal Science, Federal University of Paraíba, Areia 58397000, Brazil
[4] Department of Animal Science, Instituto Federal of Ceará, Crato 63100000, Brazil
[5] Department of Animal Science, University of Wisconsin, Madison, WI 53706, USA
* Correspondence: anderson.zanine@ufma.br

Abstract: The use of mixed ration silage (MRS) provides animals with a diet formulation that meets their nutritional requirements. This study aimed to evaluate the fermentative profile, losses, chemical composition and in vitro dry matter digestibility of mixed ration silages, including babassu by-products as a feed alternative for dairy cows. A completely randomized design was used, with four treatments and five replications, which were composed of TGS: Tanzania grass silage; MRSS: Tanzania grass silage with corn and soybean meal; MRSF: Tanzania grass silage with corn, soybean meal and babassu flour; and MRSC: Tanzania grass silage with corn, soybean meal and babassu cake. There was a significant difference between MRS and TGS ($p < 0.05$) in the variables' pH, gas (GL) and effluent losses (EL), dry matter recovery (DMR), water-soluble carbohydrates (WSC), dry matter (DM), crude protein (CP) and total digestible nutrients (TDN). There was no statistical difference in buffer capacity (BC), acid detergent lignin, hemicellulose, ether extract (EE) and aerobic stability. However, for the variables' ammonia nitrogen (NH_3-N) and non-fibre carbohydrate (NFC) content, lower values were observed in the MRS ($p < 0.001$). The babassu by-products, cake and flour, can replace corn by up to 50% of the total ration silage with Tanzania grass, meeting the nutritional requirements of dairy cows.

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

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1. Introduction

Mixed ration silage (MRS) is a viable alternative for use in animal feed that does not require daily labour to formulate ingredient mixtures, and provides animals with a diet formulated in a single mixture that meets their nutritional requirements. MRS provides animals with sources of roughage, protein and energy, additives, minerals and vitamins, in addition to reducing dry matter losses during the fermentation process [1,2].

Among the various tropical forage species cultivated in the world that can be recommended for silage production [3], Tanzania (*Panicum maximum* CV. Tanzania) grass stands out due to its high productivity and nutritive value. Its forage mass production before grazing can reach 6000 kg of DM/ha and 100 g of PB/kg of DM, and its forage residue after grazing is 2500 kg of DM/ha, making it a viable alternative use of excess forage during periods of heavy rainfall [3,4].

However, due to their physicochemical characteristics, especially their high moisture content and low water-soluble carbohydrates, silages from grass provide high loss values and usually do not reach a fermentation profile suitable for the conservation of ensiled forage [5,6]. For this purpose, the inclusion of by-products can reduce leaching losses during fermentation, in addition to improving the fermentative profile, increasing the

contents of dry matter and soluble carbohydrates, and reducing pH and N-ammoniacal, all factors that improve silage quality [7].

Palm trees of the genus *Attalea* are distributed throughout America, as well as some areas of Africa, Asia and the Middle East; these palms are producers of coconut whose almond is used for oil extraction [8]. Babassu by-products, such as mesocarp flour, can be included as silage additives, which have the potential to sequester moisture and improve the nutritional value of ruminant diets [1,9]. According to Portela et al. [9], 50% of the corn in dairy cow diets can be replaced by this by-product, thus improving silage characteristics. Therefore, the use of babassu by-products in total mixed ration can provide beneficial changes in the fermentative profile of silage due to their chemical characteristics and can reduce diet costs when compared to standard concentrates. However, there are few works in the literature that use these by-products in total ration silages.

In this way, this research aimed to evaluate the effect of mesocarp flour and babassu cake inclusion on total ration silages, based on Tanzania grass as a nutritional alternative for dairy cows.

2. Materials and Methods

2.1. Experimental Location and Conditions

The experiment was conducted at the Centre for Agricultural and Environmental Sciences of the Federal University of Maranhão (UFMA), Chapadinha, Maranhão, located at the geographic coordinates 3°43′57.8″ S 43°19′07.3″ W. The region has a hot tropical climate of the Aw type, according to the Köppen classification [10], with a rainy season from November to March and an average rainfall of 1670 mm/year.

2.2. Treatments and Experimental Design

The chemical composition of babassu by-products is shown in Table 1.

Table 1. Chemical composition of babassu by-products.

Item, %DM	Tanzania 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
ADFap [2]	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 [3]	82.33	89.6	68.4
Non-fibre carbohydrate	9.01	23.6	4.90

[1] NDFap: Neutral detergent fibre corrected for ash and protein; [2] ADFap: Acid detergent fibre corrected for ash and protein; [3] Total carbohydrates were calculated through the sum of the non-fibre carbohydrate and NDFap.

Silages in the form of mixed ration silage (MRS) were composed of 60% Tanzania grass and 40% concentrate (soybean meal, ground corn, urea, mineral salt and babassu cake or babassu mesocarp flour), replacing 50% of the corn in standard silage as energy sources.

The treatments consisted of Tanzania grass silage (TGS-control); Tanzania grass silage with corn and soybean meal (MRSS-standard diet); Tanzania grass silage with corn, soybean meal and babassu flour (MRSF); and Tanzania grass silage with corn, soybean meal and babassu cake (MRSC).

The experimental diets were formulated in the form of MRS according to NRC [11] to meet the nutritional requirements of confined dairy cows with an average weight of 500 kg, producing 15 kg/day of milk and with a DM intake of 14 kg/day.

2.3. Preparation and Ensiling of Diets

Tanzania grass was cut approximately 10 cm from the soil and chopped with a particle size of 2 cm in a silage machine coupled to the tractor. Subsequently, the cut grass was homogenised manually with the ingredients in the concentrate. Samples of this mixture were collected for evaluation of the chemical composition of the diet (Table 2).

Table 2. Chemical composition and microbial count of diets at the time of ensiling.

Item, g/kg DM	Silages			
	TGS [1]	MRSS [2]	MRSF [3]	MRSC [4]
Ingredients				
Tanzania grass	1000	600	600	600
Soybean meal	0.0	132	131	133
Corn meal	0.0	250	125	125
Babassu flour	0.0	0.0	125	0.0
Babassu cake	0.0	0.0	0.0	125
Urea	0.0	3.0	4.0	0.0
Mineral mixture	0.0	15.0	15.0	15.0
Chemical Composition				
Dry matter	226.0	317.7	304.2	299.4
Ash	85.2	77.3	82.7	76.9
Crude protein	68.2	114.0	113.5	115.0
NDFap [5]	732.0	604.8	620.8	682.8
ADFap [6]	642.0	469.7	508.5	522.2
Hemicellulose	90.0	135.1	112.3	160.6
Water-soluble carbohydrates	88.0	116.1	106.3	106.2
Lactic acid bacteria (log10 CFU/g)	3.28	3.93	3.58	3.39
Enterobacterias (log10 CFU/g)	2.45	2.12	2.25	2.37

[1] TGS: Tanzania grass silage (control); [2] MRSS: Tanzania grass silage with corn and soybean meal (standard diet); [3] MRSF: Tanzania grass silage with corn, soybean meal and babassu flour; [4] MRSC: Tanzania grass silage with corn, soybean meal and babassu cake; [5] NDFap: Neutral detergent fibre corrected for ash and protein; [6] ADFap: Acid detergent fibre corrected for ash and protein.

After homogenisation, the material was ensiled in polyethylene silos with a capacity of 3.6 L (length: 191.4 mm, height: 156.5 mm and width: 193.6 mm), equipped with a Bunsen valve for gas release.

At the base of each silo, 1 kg of dry sand was separated from the forage material by a piece of fabric to avoid contamination. The sand worked as a drainage area that was later used for effluent collection and analysis according to Jobim et al. [12].

The silos were compacted at an average density of 550 kg/m^3, weighed, sealed with a plastic lid and wrapped with adhesive tape.

2.4. Fermentative Profile

After 45 days of fermentation, the silos were weighed and opened, and the silage resulting from the fermentation process was manually removed and homogenised. Homogenised samples were stored for further analysis of the fermentation profile and the chemical composition of the silages.

The pH values were determined according to the methodology proposed by Bolsen et al. [13]; firstly, 25 g samples were homogenized with 100 mL of distilled water and then readings were taken with a glass electrode after 1 h of incubation to determine the pH.

The ammonia nitrogen content (NH_3-N/TN, in%) was determined in 15 g of silage liquefied with 100 mL of 15% potassium chloride solution for 5 min. This solution was filtered, 10 mL extracted from it, 250 mg of calcined magnesium oxide later added to it, and the solution finally distilled to determine the nitrogen content. The result was expressed as a percentage of the total nitrogen in the silage according to the methodology described by Nogueira and Souza [14].

Microbial groups were counted in the aqueous extract, obtained by mixing 10 g of silage sample and 90 mL of phosphate buffer solution in an industrial blender for 1 min, obtaining the dilution of 10^{-1}. Afterwards, samples were successively diluted to obtain the concentration range from 10^{-1} to 10^{-9}, and agar plates with values between 30 and 300 colony-forming units (CFU) were counted. Plating was performed in duplicate on sterile Petri plates immediately after preparing the aqueous extract. The data were presented as log 10 CFU g^{-1} forage. Sample collection for microbiological analysis was carried out at the time of opening the experimental silos. Microbial populations were counted using selective culture media for each microbial group: MRS (Difco) for enumeration of lactic acid bacteria (LAB) after incubation for 48 h in a BOD oven at 39 °C; Violet Red Bile Agar (Difco) for counting enterobacteria (ENT) after incubation for 24 h in a BOD oven at 30 °C [15].

Organic acids (lactic acid, acetic acid, propionic acid and butyric acid) were determined using 25 g of the silage liquefied with 225 mL of water for 1 min, and subsequently collecting 10 mL of the solution filtered on filter paper. Then, 2 drops of concentrated sulfuric acid and 5 mL of metaphosphoric acid were added. After that, the samples were homogenised by vortexing for 10 min at 15,000 rpm. The supernatant was collected and analysed in high-performance liquid-phase chromatography (HPLC) according to Siegfried et al. [16].

The buffering capacity (BC) was analysed according to Zanine et al. [17], using approximately 15 g of the macerated sample and 250 mL of distilled water. Using a potentiometer, the material was first titrated to pH 3.0 with 0.1 N HCL to release the bicarbonates as carbon dioxide and then titrated to pH 6.0 with 0.1 N NaOH, recording the volume of NaOH spent to change the pH from 4.0–6.0.

Dry matter losses in silages, in the form of gases and effluents, were quantified by weight difference according to methodologies proposed by Jobim et al. [12] and adapted by Zanine et al. [17].

Gas losses were obtained by use of the following equation:

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

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

Using the difference in weight (from the beginning to the end of the experimental silo) of sand placed at the bottom of the vessel, the effluent losses were calculated using the following equation:

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

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

2.5. Chemical Composition Analysis

Samples of fresh material were collected for chemical composition evaluation before ensiling and after opening of the silos. These samples were pre-dried in a forced-air 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, labelled, and subjected to dry matter (DM; method 934.01), ash (method 930.05), crude protein (CP; method 920.87) and ether extract (EE; method 920.39) analyses [18]. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to Van Soest et al. [19].

To obtain the ash and protein-corrected neutral detergent fibre (NDFap) contents, the NDF residue was incinerated in an oven at 600 °C for 4 h and corrected for protein by subtracting the neutral detergent-insoluble nitrogen (NDIN). The NDIN and acid detergent-insoluble nitrogen (ADIN) contents were determined according to the methods of Licitra et al. [20]. Acid detergent lignin (ADL) was determined according to method 973.18 (AOAC, 2012). Hemicellulose (HEM) was calculated as the difference between NDFap and ADFp, and cellulose (CEL) as the difference between ADFp and ADL.

Total carbohydrates (TC) were calculated according to Sniffen et al. [21]. The concentration of non-fibrous carbohydrates (NFC) was estimated from the equation, NFC = 100 − (%CP + %NDFap + EE + Ash), as proposed by Detmann et al. [22]. The soluble carbohydrate content was determined according to Dubois et al. [23] using concentrated sulfuric acid. Total digestible nutrients (TDN) were estimated according to Van Soest [6]. In vitro dry matter digestibility (IVDMD) was obtained after 48 h of incubation and the residue was washed with neutral detergent and weighed after drying at 105 °C in a forced-air oven for 24 h.

2.6. Aerobic Stability

The silage samples were placed, without compaction, in experimental PVC silos with a capacity of 5 kg without a lid and kept in a temperature-controlled closed environment at 25 °C.

Aerobic stability was evaluated by monitoring the internal temperature of silages exposed to air, using encapsulated temperature sensors (DS18B20-Maxim Integrated™, DS18B20, California, United States, operating temperature range −55 to 125 °C, accuracy ±0.5 °C) and interconnected to a specific microcontroller (Atmega2560–Arduino®, Mega 2560, Italy), programmed to record the temperature every minute for a 120 h period.

The sensors were inserted in the centre of the silo's mass, at a depth of 15 cm. The point when the silage's internal temperature reached 2 °C above room temperature was considered the beginning of deterioration [24].

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:

$$Y_{ik} = \mu + S_i + \varepsilon i_k, \quad (4)$$

where:

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® [25] software was used. The data were submitted for analysis of variance and the means compared by using Tukey's test. p values less than 0.05 were considered indicative of significance.

3. Results

Evaluation of the data regarding the fermentation profile and silage losses produced a significant difference (Table 3) for the variables' pH ($p < 0.001$), NH_3-N ($p < 0.001$), microbial count ($p = 0.001$), gas losses (GL, $p < 0.001$), effluent losses (EL, $p < 0.001$), dry matter recovery (DMR, $p = 0.001$) and water-soluble carbohydrates (WSC). However, there was no significant difference in the buffer capacity (BC, $p < 0.331$).

Table 3. Fermentation profile, losses and values of organic acids (%DM) of total ration silages with babassu by-products.

Item	Silages				SEM	*p*-Value
	TGS [1]	MRSS [2]	MRSF [3]	MRSC [4]		
pH	5.15 [b]	5.10 [bc]	5.08 [c]	5.26 [a]	0.02	<0.001
Buffer capacity (E. mg NaOH)	0.806	0.774	0.846	0.846	0.02	0.331
NH_3-N (% N total)	11.19 [a]	8.37 [b]	8.84 [b]	8.62 [b]	0.30	<0.001
Gas losses (%DM)	0.214 [a]	0.105 [b]	0.108 [b]	0.117 [b]	0.01	<0.001
Effluent losses (kg/ton)	23.89 [a]	13.02 [b]	14.82 [b]	14.77 [b]	1.14	<0.001
Dry matter recovery (%DM)	85.93 [b]	94.68 [a]	95.09 [a]	95.39 [a]	1.20	0.001
Water-soluble carbohydrates (g/kg DM)	55.4 [b]	90.8 [a]	82.4 [a]	80.2 [a]	0.38	0.001
Lactic acid bacteria (log10 CFU/g)	6.45 [b]	7.53 [a]	7.72 [a]	7.61 [a]	0.28	0.001
Enterobacterias (log10 CFU/g)	3.65 [b]	1.28 [a]	1.15 [a]	1.31 [a]	0.11	0.001
Lactic acid (g/kg DM)	40.15 [b]	51.91 [a]	51.22 [a]	52.08 [a]	0.25	<0.001
Acetic acid (g/kg DM)	2.80	3.37	3.52	3.53	0.05	0.224
Butyric acid (g/kg DM)	2.62 [a]	2.23 [b]	2.17 [b]	2.24 [b]	0.01	<0.001
Propionic acid (g/kg DM)	1.20	1.31	1.28	1.44	0.28	0.125
Ethanol (g/kg DM)	14.3	12.41	12.61	13.11	0.25	0.139
LA:FP (%) [5]	65.74 [b]	72.87 [a]	72.34 [a]	71.93 [a]	0.07	<0.001

[1] TGS: Tanzania grass silage (control); [2] MRSS: Tanzania grass silage with corn and soybean meal (standard diet); [3] MRSF: Tanzania grass silage with corn, soybean meal and babassu flour; [4] MRSC: Tanzania 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.

The highest pH value was observed for Tanzania grass silage containing corn, soybean meal, and babassu cake (MRSC), and the lowest value was observed for Tanzania grass silage containing corn, soybean meal and babassu flour (MRSF, $p < 0.001$).

However, for the NH_3-N variable, mixed-ration silages (MRS) showed lower values than TGS ($p < 0.001$). Higher losses of gases and effluents were observed for TGS than for MRS ($p < 0.001$) (Table 3).

MRS showed higher water-soluble carbohydrates than TGS ($p < 0.001$). The same significant differences were observed in some organic acids, lactic acid (LA, $p < 0.001$) and butyric acid (AB, $p < 0.001$), as well as LA:FP ($p < 0.001$). However, there were no significant differences in the contents of acetic acid (AA, $p = 0.224$), propionic acid (PA, $p = 0.125$) and ethanol ($p = 0.139$).

Lactic acid concentrations were higher in MRS than in TGS. For butyric acid, the highest value was observed in TGS. MRS showed the lower contents of these organic acids, but there was no significant difference ($p > 0.05$) between the MRS.

The chemical composition of the silages is shown in Table 4. Higher values of dry matter (DM, $p < 0.001$), crude protein (CP, $p < 0.001$), total digestible nutrients (TDN, $p = 0.005$) and in vitro dry matter digestibility (IVDMD, $p = 0.004$) were observed for MRS in relation to TGS ($p < 0.001$). However, for neutral detergent fibre corrected for ash and protein (NDFap, $p < 0.001$), and for the acid detergent fibre (ADF, $p < 0.001$), the highest values were observed for TGS.

The variables' total carbohydrates (TC, $p < 0.001$) and non-fibrous carbohydrates (NFC, $p < 0.001$) differed between silages, and MRS showed lower values of total carbohydrates in relation to TGS. For NFC content, MRS showed higher values compared to TGS silage. However, the inverse was observed for the cellulose contents (CEL, ($p < 0.001$), i.e., the highest contents were observed in the TGS treatment compared to the MRS and there was no significant difference between the MRS formulations.

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

Item (g/kg DM)	Silages				SEM	*p*-Value
	TGS [1]	MRSS [2]	MRSF [3]	MRSC [4]		
Dry matter	206.30 [b]	274.25 [a]	267.39 [a]	276.95 [a]	6.879	<0.001
Ash	105.07 [a]	87.54 [c]	98.09 [b]	93.69 [b]	1.593	<0.001
Organic matter	894.93 [b]	912.46 [a]	901.91 [a]	906.91 [a]	2.816	<0.001
Crude protein	65.53 [b]	125.77 [a]	129.58 [a]	130.51 [a]	6.193	<0.001
NDFap [5]	710.05 [a]	566.29 [b]	589.79 [b]	609.21 [b]	13.67	<0.001
ADFp [6]	606.43 [a]	458.62 [c]	482.71 [bc]	506.41 [b]	1.373	<0.001
Acid detergent lignin	130.61	120.43	161.28	116.39	8.221	0.209
Hemicellulose	103.62	107.68	107.08	102.8	0.892	0.997
Cellulose	475.81 [a]	357.68 [b]	362.59 [b]	358.21 [b]	1.340	<0.001
Ether extract	17.45	21.75	19.93	21.25	0.125	0.599
Total carbohydrates	80.87 [a]	76.55 [b]	75.28 [b]	77.02 [b]	0.521	<0.001
Non-fibre carbohydrate	9.87 [b]	19.82 [a]	16.30 [a]	16.10 [a]	1.008	<0.001
Total digestible nutrients	594.01 [b]	727.34 [a]	650.96 [a]	657.56 [a]	15.22	0.005
In vitro digestibility of DM	522.69 [b]	642.21 [a]	620.31 [a]	627.91 [a]	14.37	0.004

[1] TGS: Tanzania grass silage (control); [2] MRSS: Tanzania grass silage with corn and soybean meal (standard diet); [3] MRSF: Tanzania grass silage with corn, soybean meal, and babassu flour; [4] MRSC: Tanzania grass silage with corn, soybean meal, and babassu cake; [5] NDFap: neutral detergent fibre corrected for ash and protein; [6] ADFp: acid detergent fibre corrected for protein; 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.

For maximum temperature and aerobic stability, no significant differences ($p > 0.05$) were observed among the studied silages (Table 5).

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

Item	Silages				SEM	*p*-Value
	TGS [1]	MRSS [2]	MRSF [3]	MRSC [4]		
Ambient temperature (°C)	25.0	25.0	25.0	25.0	——	——
Aerobic stability (hours)	>114	>114	>114	>114	——	——
Max temperature in 120 h (°C)	25.5	25.6	25.6	26.0	0.16	0.233
Hours/Max temperature	48.7	20.3	8.1	32.0	11.1	0.115

[1] TGS: Tanzania grass silage (control); [2] MRSS: Tanzania grass silage with corn and soybean meal (standard diet); [3] MRSF: Tanzania grass silage with corn, soybean meal and babassu flour; [4] MRSC: Tanzania grass silage with corn, soybean meal and babassu cake; SEM: standard error of the mean.

4. Discussion

The formulation of MRS resulted in an increase in the dry matter, protein and soluble carbohydrates content of the ensiled material. The dry matter content of Tanzania grass is below the values recommended by McDonald et al. [26] of 28–34%, which could favour undesirable fermentations and thus raises the final pH values of the silage. However, in addition to higher dry matter values, MRS also provided a higher concentration of soluble carbohydrates, which aid in the proliferation of lactic acid bacteria (LAB, >7.50 log10 CFU/g) and the consequent sharper drop in pH, thus inhibiting undesirable fermentations (Enterobacterias, <2 log10 CFU/g) (Table 3) [24,26].

According to McDonald et al. [24], the pH should be between 3.8 and 4.2 for proper silage fermentation; thus, the Tanzania grass silages (control) showed the possibility of a higher rate of undesirable fermentation due to their high final pH and higher NH_3-N values.

According to Woolford and Pahlow [27], a moisture content above 75% can promote the proliferation of bacteria of the genera *Clostridium* and *Enterobacter*, which use the carbohydrates and proteins present in silages as substrates for their growth. This results in greater losses through gases and effluents, and consequently a lower recovery of dry matter and soluble carbohydrates.

The MRS showed higher values of lactic acid and lower values of butyric acid, demonstrating that the increase in DM and soluble carbohydrates in the ensiled material promoted an increase in the population of LAB [28], which favoured a more accentuated drop in pH even with final pH values above those recommended by McDonald et al. [26].

Ammonia nitrogen values above 5% total nitrogen, as recommended by Roth and Undersander [29], may have contributed to the elevation of the final pH of all silages, evidencing undesirable fermentation. These undesirable fermentations may promote an inhibitory effect on the dry matter intake by animals. Tanzania grass silage (control) presented a higher concentration of butyric acid and ammonia, which may result in lower diet acceptability, due to the inversely proportional relationship with DM intake [30].

The concentration of lactic acid in the silage through the presence of LAB, which can be homo- or heterofermentative, was measured. Both groups are important for the fermentation of the material and, consequently, the conservation of bromatological fractions and stability of the silage, in addition to the decrease in pH and greater fermentation efficiency [28]. The main difference between homo- and heterofermentative LAB is related to the production of other organic acids in the silage, such as propionic acid, acetic acid and 1,2 propanediol, which have an inhibitory effect on ethanol-producing yeasts [24]. These organic acids did not show differences between Tanzania grass silages and MRS, but the propionic acid concentrations remained within the recommended limit for good-quality silages [29].

Another indicator of fermentation quality in silages is an LA:FP ratio in the range of 60%–85% and lactic acid in the range of 40–60 g/kg of DM, with maximum values of 20 g/kg of DM for acetic acid, 5 g/kg of DM for propionic acid and ethanol and 1 g/kg of DM for butyric acid, according to Roth and Undersander [29]. A higher LA:FP promotes a lower pH value.

Gas losses and effluents (kg/ton organic matter) were lower in MRS, evidencing the ability of the concentrates to absorb the moisture in grass silage This lowered the incidence of undesirable fermentation and reduced the water activity, as well as the presence of gas-producing microorganisms, such as enterobacteria, clostridial bacteria and especially yeasts [31]. There were no differences among the different MRS formulations, demonstrating that the inclusion of babassu by-products maintains the fermentative and bromatological parameters of silage and can be a viable alternative in the production of MRS.

The higher DM values in the MRS provided an improvement in the bromatological composition of the ensiled material, mainly via the contribution of soluble carbohydrates; this resulted in a higher DMR, with averages close to 95% [32], indicating the efficiency of the use of babassu by-products in silages in the ruminant's diet. Portela, et al. [9] tested the inclusion of babassu by-products in sugarcane silages and reported similar results.

According to Tomich et al. [33], silages can be scored according to DM and pH, the presence of ammonia nitrogen, and the contents of butyric and acetic acids as excellent (90–100), good (70–89), regular (50–69), bad (30–49) and very bad (<30). All silages in this work were classified as regular, with scores of 55 for TGS and 60 for MRS, suggesting that higher proportions of concentrate in STR can improve the fermentative profile of silages.

Gusmao et al. [2] reported that the addition of soluble carbohydrates favoured the growth of lactic acid bacteria, which increased lactic acid production and improved silage fermentation, decreasing effluent and gas losses, and increasing DM recovery. In this study, our silages had a lower dry matter content than those reported on by Gusmão et al. [2], so the fermentative profile of our silages showed a higher incidence of undesirable fermentation.

Mixed ration silage showed a reduction in the contents of NDFap, ADFp and cellulose, which represent the cell wall components of plants responsible for limiting DM intake by animals; thus, MRS provided a greater available nutrient supply to the animals, resulting in an improvement in ruminant performance [34].

Gusmão et al. [2], when evaluating MRS based on elephant grass, found a similar behaviour for the reduction of NDF levels and higher levels of NFC, in relation to the

control treatment. The increase in the concentration of NFC and CP from MRS, generates in the rumen a greater production of volatile fatty acids that represent the main energy source for ruminants, meeting up to 80% of the daily nutritional requirements [35]. In addition, the use of carbohydrates by ruminal microorganisms favours the maximisation of microbial protein (MP) synthesis and, consequently, better diet utilization [36].

Aerobic stability is an important variable related to silage deterioration. The literature reported that lower aerobic stability values, among other factors such as the storage period, are related to the pH of the silage [2,36]. Aerobic spoilage is caused by the depopulation and growth of yeasts, which oxidize the soluble carbohydrate residue and the preservative acids in the silage, a process which in turn generates heat [37]. In the present study, all silages presented more than 114 h and the temperature in the silages reached a maximum of 26 °C. There were no fluctuations or elevations in the temperature of the silages while they were exposed to the air.

5. Conclusions

The babassu by-products cake and starchy flour can replace 50% of the corn in Tanzania grass silages, meeting the criteria for total ration silage. The composite silages were a proven equivalent to standard concentrates in their fermentation profiles and chemical composition; moreover, their use could reduce the costs of diets for medium-production dairy cows (depending on availability in the region).

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