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Intake, digestibility, and nitrogen balance of rations containing different levels of murumuru meal in sheep diets

Consumo, digestibilidade e balanço de nitrogênio de rações contendo diferentes teores de torta de murumuru em dietas para ovinos

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Abstract

This study aimed to assess the potential use of increasing levels of murumuru cake (*Astrocaryum murumuru* var. murumuru, M art.) (MC) in sheep diets as a replacement for Mombasa grass (*Panicum maximum* Jacq). Metabolic tests were performed with 20 castrated male sheep at Embrapa Amazônia Oriental, Belém, Pará, during 26 days. The experiment was arranged in a completely randomized design, with five diets and four replications. MC0: 100% grass; MC10: 10% MC and 90% grass; MC20: 20% MC and 80% grass; MC40: 40% MC and 60% grass; and MC60: 60% MC and 40% grass. The intake and the coefficient of apparent digestibility of dry matter (DMI and CDDM), organic matter (OMI and CDOM), crude protein (CPI and CDCP), neutral detergent fiber (NDFI and CDNDF), acid detergent fiber (ADFI and CDADF), ether extract (EEI and CDEE), cellulose (CELI and CDCEL), hemicellulose (HEMI and CDHEM), and nitrogen balance (NB) of experimental diets were determined. The intake of mineral material (MMI) and lignin (LIGI) were also determined. The DMI, OMI, MMI, CPI, NDFI, and ADFI displayed a decreasing linear effect with the replacement of Mombasa grass by MC in the diet. The EEI and the LIGI presented quadratic effects according to the replacement levels of MC in the diet. The CDDM, CDOM, and CDHEM displayed increasing linear effects, between MC0 and MC60. The CDEE, CDNDF, CDADF, and CDCEL displayed a quadratic effect, with optimum replacement levels of 56.65%, 41%, 31.33%, and 27.46%, respectively. The nitrogen balance presented a negative linear effect in the range of 0% to 60% of murumuru cake. One can conclude that murumuru cake is an alternative to the dietary supplementation of ruminants in replacing the Mombasa grass because it

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provides an increase in the digestibility of nutrients for sheep. However, a limited replacement level must be implemented, considering that from 27.46%, 31.33%, 41%, and 56.65% replacement, a decline occurs in the CDCEL, CDADF, CDNDF, and CDEE, respectively, although a negative nitrogen balance does not occur.

Key words: Amazon, ruminants, agroindustrial by-product, dietary supplements

Resumo

A pesquisa objetivou estudar o potencial de utilização da torta de murumuru (*Astrocaryum murumuru* var. murumuru, M art.) (TM) em dietas de ovinos, em substituição à gramínea Mombaça (*Panicum maximum* Jacq) com teores crescentes. Realizou-se ensaio metabólico, com 20 ovinos machos, castrados, na Embrapa Amazônia Oriental, Belém, Pará, durante 26 dias. O delineamento foi inteiramente casualizado, em cinco dietas e quatros repetições. TM0: 100% de gramínea; TM10: 10% de TM e 90% de gramínea; TM20: 20% de TM e 80% de gramínea; TM40: 40% de TM e 60% de gramínea e TM60: 60% de TM e 40% de gramínea. Foram avaliados o consumo e o coeficiente de digestibilidade aparente da matéria seca (CMS e CDMS), matéria orgânica (CMO e CDMO), proteína bruta (CPB e CDPB), fibra em detergente neutro (CFDN e CDFDN), fibra em detergente ácido (CFDA e CDFDA), extrato etéreo (CEE e CDEE), celulose (CCEL e CDCEL), hemicelulose (CHEM e CDHEM) e balanço de nitrogênio (BN) das dietas experimentais. O CMS, CMO, CMM, CPB, CFDN e CFDA apresentaram efeito linear decrescente em função dos teores de substituição da gramínea Mombaça por TM na dieta. O CEE e o CLIG apresentaram efeitos quadráticos em função dos teores de substituição da TM na dieta. O CDMS, CDMO e CDHEM tiveram efeitos lineares crescentes, entre TM0 e TM60. O CDEE, CDFDN, CDFDA e CDCEL apresentaram efeito quadrático, com teores de substituição ótimos de 56,65%, 41%, 31,33% e 27,46%, respectivamente. O balanço de nitrogênio apresentou efeito linear negativo no intervalo de inclusão de 0% a 60% de torta. Conclui-se que a torta de murumuru constitui alternativa para a suplementação alimentar de ruminantes, em substituição à gramínea Mombaça, pois proporciona aumento na digestibilidade dos nutrientes por ovinos. Entretanto, deve-se respeitar um limite de inclusão, considerando-se que a partir de 27,46%, 31,33%, 41% e 56,65% de substituição ocorrem decréscimos, respectivamente da CDCEL, CDFDA, CDFDN e CDEE, embora não ocorra valor negativo para o balanço de nitrogênio.

Palavras-chave: Amazônia, ruminantes, subproduto agroindustrial, suplementação alimentar

Introduction

The Brazilian sheep herd includes approximately 17 million animals (IBGE, 2014), making Brazil the 15th largest producer in the world (FAO, 2007). In the Amazon, this number is growing because conditions are favorable for production of good quality forage owing to the abundant supply of radiant energy and rainfall. However, one of the main obstacles in rearing systems for ruminants is the low profitability of traditional livestock, in which the nutritional demand of the animal is not fulfilled, especially in the dry season, with reduced forage mass. Thus, the use of animal by-products from agribusiness is an alternative to fill this need because it reduces the cost of animal feed, which makes up a large portion of total production costs. Thus, it is important to identify the nutritional characteristics of alternative foods in order to increase the inclusion of these foods as a substitute for conventional food.

Murumuru (*Astrocaryum murumuru var. murumuru* Mart.) is a typical Amazon palm, with a visually appealing and exuberant stature, and can reach up to 10 m in height (NASCIMENTO et al., 2007; ROCHA; POTIGUARA, 2007). Amazon communities know the fiber properties of the leaves and stem, and its edible palm oil and palmetto (MIRANDA et al., 2001), although it is little exploited commercially, probably because of the difficulty in handling due to numerous thorns. Currently, there are cosmetic products in the market that use oils extracted from its fruits as raw material (ROCHA; POTIGUARA, 2007). When the fruits ripen, the entire fruit bunch falls to the ground, acting as an important food source for local fauna. The fruits are composed of pulp and nut. The latter contains about 50% of a white, odorless, and tasteless fat with the advantage of not becoming rancid easily and being rich in short-chain saturated fatty acids, such as lauric and myristic acid. The murumuru nut has a 40% mass oil content (NASCIMENTO et al., 2007). Murumuru cake is a by-product that arises from the extraction of oil from the dry seed by mechanical pressing, through which 80% of the total seed oil is extracted.

The viability of the use of agribusiness by-products in ruminant diet requires the determination of their nutritional value and that of feed containing different levels of these ingredients. Thus, the present study aimed to evaluate the potential use of murumuru cake in sheep diets as a replacement for Mombasa grass (*Panicum maximum* Jacq) through the determination of the intake, digestibility, and nitrogen balance.

Material and Methods

The experiment was carried out on the “Senador Álvaro Adolpho” Animal Research Unit (1º28’ S and 48º27’ W), belonging to Embrapa Amazônia Oriental, Belém, Pará, from June to July of 2010. *P. maximum* Jacq cv. Mombasa grass was used, which received 36 kg of NPK fertilization (10:28:20) in its deployment in an area of 1,800 m^2, divided into 30 paddocks of 60 m^2 (10 m × 6 m). A complete leveling of the selected area was performed to regulate grass height and, after 30 days, a daily cut was carried out (25 cm from the ground) to obtain grass of the same physiological stage, with 30 days of rest.

Voluntary intake and apparent digestibility were estimated using 20 male, castrated, dewormed, sheep, of an unspecific breed, with an average body weight of 25 kg, kept in individual metabolic cages during the 26-day experimental period. The first 21 days of this period were for adaptation and the remaining 5 days were for collection of feed provided, leftovers, feces, and urine. The feces were collected with the aid of plastic sheeting that was inserted perpendicularly from the middle of the bottom of the cage to the external rear side of the cage, at an angle of 45º, which directed the feces to the collection boxes, where samples were obtained once a day. To avoid contamination between feces and urine, the urine samples were collected using collector funnels adapted to the animals. These funnels were attached to rubber hoses directing the urine to plastic containers containing 20 mL of hydrochloric acid (HCl) 1:1 to avoid the proliferation of bacteria and possible losses by volatilization. Twenty percent of the total volume of excreted urine was withdrawn per animal. Urine samples were obtained from the penultimate day of the experimental period, in 24-hour collections (VALADARES et al., 1997). Daily and individual samples of feed, leftovers, urine, and feces were kept in a freezer until the end of the test, when they were analyzed per animal, within each phase.

The diet of the animals consisted of Mombasa grass and different levels of replacement by murumuru cake (MC), both provided, based on dry matter, twice a day (0800 and 1500) and adjusted daily to provide 10% of leftovers in the natural material, in addition to water and mineral salt *ad libitum*. The grass was cut in the early morning, chopped, and manually mixed with experimental ration. The leftovers were weighed every morning, prior to delivery of the first meal of the day, to determine feed intake by the animals and intake adjustment.

The animals were subjected to five diets: MC0 = 100% grass; MC10 = 90% grass + 10% MC; MC20 = 80% grass + 20% MC; MC40 = 60% grass + 40% MC; and MC60 = 40% grass + 60% MC. The diets were formulated according to the National Research Council (NRC, 1985) in order to meet the nutritional requirements for lambs in termination of 25 kg of live weight and an average daily gain of 200 g. The feed was sampled before the morning meal and the leftovers and feces were collected and weighed. The samples were packed in plastic bags, identified, and stored in a freezer at -20°C. At the end of the experimental period, samples were thawed at room temperature and homogenized for preparation of composite samples and subsequent analyses. The samples of feed, leftovers, and feces were pre-dried in an oven at 55°C, with forced air ventilation, for approximately 72 hours, then crushed in a mill with a 1-mm sieve mesh and wrapped in plastic containers for subsequent analyses (SILVA; QUEIROZ, 2006).

The analyses were performed at the Laboratory of Animal Nutrition the Universidade Federal da Amazônia - UFRA and at the Soil Laboratory of the Instituto Federal de Educação, Ciência e Tecnologia do Pará - IFPA/Campus Castanhal. Analyses of dry matter (DM), organic matter (OM), and mineral material (MM) in feed, leftovers, and feces were performed according to the recommendations of the Association of Official Analytical Chemists (AOAC, 2005). The neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose (CEL), hemicellulose (HEM), and lignin (LIG) were assessed by the sequential method, described by Van Soest et al. (1991). The determination of crude protein (CP) was performed using the Kjeldahl method (AOAC, 2005). The ether extract (EE) was determined according to the recommendations by Silva and Queiroz (2006). The chemical composition of the ingredients of experimental diets and total diet, in terms of dry weight, are presented in Table 1.

Table 1. Chemical composition of murumuru cake (*A. murumuru* var. murumuru Mart.), Mombasa grass (*P. maximum* cv. Mombasa), and different replacement levels of Mombasa grass by murumuru cake (MC0, MC10, MC20, MC40, and MC60).

Diet	Variable (% in DM)												
	DM	MM	OM	EE	CP	NDF	ADF	CEL	HEM	LIG	TDN	NIDA	NDIN
Murumuru cake	89.02	1.59	98.41	16.32	9.92	83.91	64.27	35.68	19.64	28.59	-	44.80	59.11
Mombasa	23.04	8.52	91.48	1.80	9.56	62.20	50.14	44.42	12.06	5.72	-	24.28	33.26
MC0	23.04	8.52	91.48	1.80	9.56	62.20	50.14	44.42	12.06	5.72	58.58	-	-
MC10	29.64	7.83	92.17	3.25	9.60	64.37	51.55	43.55	12.82	8.01	63.77	-	-
MC20	36.23	7.13	92.86	4.70	9.63	66.54	52.96	42.67	13.57	10.29	66.13	-	-
MC40	49.43	5.74	94.25	7.60	9.70	70.88	55.97	40.92	15.09	14.86	67.65	-	-
MC60	62.62	4.46	95.63	10.51	9.77	75.22	58.61	39.17	16.60	19.44	71.63	-	-

DM: dry matter; MM: mineral material; OM: organic matter; EE: ether extract; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; CEL: cellulose; HEM: hemicellulose; LIG: lignin; TDN: total digestible nutrients; %TDN: (TDN Consumed/DM Consumed) x 100 (SNIFFEN et al., 1992); NIDA: insoluble nitrogen in acid detergent; NIDN: insoluble nitrogen in neutral detergent.

The intake of dry matter (DMI), organic matter (OMI), crude protein (CPI), ether extract (EEI), neutral detergent fiber (NDFI), acid detergent fiber (ADFI), cellulose (CELI), hemicellulose (HEMI), and lignin (LIGI), and the coefficients of apparent digestibility of dry matter (CDDM), organic matter (CDOM), crude protein (CDCP), neutral detergent fiber (CDNDF), and acid detergent fiber (CDADF) were determined by total collection of feces. In the calculation of the apparent digestibility coefficients of DM, OM, CP, EE, NDF, and ADF, we adopted the formula indicated by Silva and Leão (1979), ADCN (%) = (NCON - NEXC)/NCON) × 100, where: ADCN = apparent digestibility coefficient of nutrients; NCON = quantity of nutrient consumed in grams, and NEXC = quantity of nutrient excreted in the feces, in grams. The levels of total nitrogen in urine were measured by the Kjeldahl method, following the procedures described by Silva and Queiroz (2002).

The calculation of nitrogen retained (N-retained), nitrogen absorbed (N-absorbed), and nitrogen balance (NB) were obtained by the formulas proposed by Silva and Leão (1979), as follows: N-retained = (N Supplied - N Leftovers) - (N Feces + N Urine); N-absorbed = (N Supplied - N Leftovers) - N Feces; and NB = N ingested - N fecal - N urinary.

The experimental design was completely randomized, with five diets and four replications, using the Statistical Analysis System (SAS, 2003) software. Regression analysis was performed in order to assess the effects of the diets on voluntary intake, digestibility, and nitrogen balance. The data were subjected to analysis of variance, in accordance with the statistical regression model. The significance of the effects studied was verified by the F test. All tests were performed with a significance of 0.05.

Results and Discussion

Murumuru cake presented similar levels of DM to those of other by-products from processing oilseeds by agribusiness, such as palm (BARBOSA et al., 2010; COSTA et al., 2010; OLIVEIRA et al., 2007) and cocoa meal (SILVA et al., 2005). Rodrigues Filho et al. (1993) assessed the levels of OM of by-products of palm oil in Belém, Pará, and obtained values of 95.5% and 95.1%, respectively, for almond cake and pulp fiber, similar to those found in murumuru cake in this study (Table 1).

The level of EE in murumuru cake, 16.32%, is higher than that found in other by-products, such as palm oil cake, with 8.23% of EE (BARBOSA et al., 2010) and cocoa meal, with 9.9% of EE (CARVALHO et al., 2007). The level of CP in murumuru cake (9.92%), on the other hand, is lower than that of palm oil cake (16.62%) found by Barbosa et al. (2010) and cocoa meal (13.5%), reported by Carvalho et al. (2007). However, the content of CP in murumuru cake was higher than 7%, which is considered the minimum to impede a decrease in voluntary intake and digestibility of dry matter in ruminants (OJEDA; WERNWLI, 1990).

Barbosa (2010) observed that the values of NDF and ADF found in murumuru cake were much higher than those found in palm oil cake, which were 7.4% for NDF and 18.1% for ADF. Diets with a high percentage of NDF may cause a reduction in the intake of DM when used in ruminant feed because of the high fiber content (ALLEN, 2000), which reduces the rate of ruminal passage and increases the retention time of the food in the rumen.

The CEL content of murumuru cake is within the acceptable variation, based on 20% to 40% of DM in higher plants (VAN SOEST, 1994). However, when comparing different parts of the plant or vegetable by-products, the variation becomes broader (GIGER-REVERDIN, 1995). Moreover, the high degree of lignification of the cell wall may become a predominant factor in the reduction of digestibility in diets with high levels of cake because of the difficulty of colonization and breakdown by microorganisms in the particles of this ingredient (VAN SOEST, 1994). In the present study, the values of 36.68% CEL, 19.64% HEM, and 28.59% LIG were higher than those found by Carvalho et al. (2007) in cocoa meal (23.1% CEL, 8.5% HEM, and 17.9% LIG). This high quantity of lignin is perhaps closely linked to the processing of the fruit during oil extraction, which raises the temperature during crushing through stainless steel presses, which in turn leads to the formation of artificial lignin. Considering the chemical composition, therefore, murumuru cake behaves as grass feed.

Mombasa grass presented similar DM percentages to those found by Garcia et al. (2009), with values ranging from 20.90% to 22.85%. This finding was in agreement with the data reported by Ferreira et al. (2007), in the range of 20% for this type of forage. These DM values can be considered normal for the Mombasa variety. This observation confirms the stability of the system used to maintain ideal nutrition and similar characteristics in the course of the study. The OM obtained in the experiment was similar to that obtained by Oliveira et al. (2007), who observed an average of 89.29% for the Mombasa grass.

The mean value of CP in the grass was 9.56%. This result is similar to results obtained by Garcia et al. (2009) in silvopastoral systems; however, Costa et al. (2004) reported values between 10 and 12%. These values may be explained by seasonal variation in rainfall. The experimental period normally displays lower rainfall indices than other periods of the year, resulting in less displacement of CP to the leaf area, which probably influenced the NDF and ADF values.

The levels of DM, OM, EE, NDF, ADF, HEM, and LIG increased with the levels of murumuru cake in the experimental diets. Major changes in the levels of CP did not occur because the CP of the grass and cake are similar. Murumuru cake has a high fiber content, which changed the density of the feed. This change can influence the absorption of water and reduce intake, owing to the volume occupied in the digestive tract. The increase in the percentage of ADF in the diets with murumuru cake could have provided a high level of indigestible residues in the rumen (mainly lignin), high levels of phenolic compounds, a lower rate of passage, and stagnation of the diet in the gastro-intestinal tract.

The levels of EE in murumuru cake (40% and 60% of cake) exceeded the maximum recommended level (7% of the total diet). At this level, lipids can negatively affect the intake of nutrients, either through regulatory mechanisms that control food intake, or because of the limited ability of ruminants to oxidize fatty acids (MAIA, 2006; PALMQUIST; MATTOS, 2006).

DMI displayed a negative linear effect (Table 2), with each 1% of cake causing a reduction in intake in the order of 4.94 g. The lowest content was obtained with MC60, with a mean intake of 260.7 ± 38.1 $g \cdot day^{-1}$, according to the equation $Y = -4.940X + 638.03$. This result may have been influenced by the level of EE in the diet, being affected by ruminal fermentation, intestinal motility, the acceptability of feed, the release of intestinal hormones, and fat oxidation in the liver (ALLEN, 2000). This negative effect on ruminal fermentation is attributed to the presence of free fatty acids, the ability to form insoluble salts, and the capacity to develop a physical barrier around the feed, which hampers microbial colonization (PALMQUIST, 1989).

Table 2. Intake in sheep fed diets with different replacement levels of Mombasa grass (*P. maximum* cv. Mombasa*)* by murumuru cake (*A. murumuru* var. murumuru, Mart.).

Variable (g/day)	Replacement level by murumuru cake					RE	R²	P	CV (%)
	0%	10%	20%	40%	60%				
DMI	609.7	589.5	513.6	573.9	260.7	$Y = -4.94X + 638.03$	0.43	0.0017	25.29
OMI	557.8	543.38	477.0	540.9	249.3	$Y = -4.315X + 585.83$	0.39	0.0030	25.58
MMI	51.9	46.2	36.6	32.9	11.4	$Y = -0.630X + 52.18$	0.76	0.0001	22.21
CPI	58.3	56.6	49.4	55.7	25.4	$Y = -0.462X + 61.12$	0.41	0.0002	25.43
EEI	11.0	19.2	24.1	43.6	27.4	$Y = -0.018X^2 + 1.446X + 8.10$	0.66	0.0002	30.71
NDFI	379.3	379.5	341.7	406.3	196.1	$Y = -2.426X + 403.64$	0.27	0.0180	26.58
ADFI	305.7	303.9	272.0	320.2	152.8	$Y = -2.055X + 324.33$	0.30	0.0126	26.37
CELI	270.8	256.7	219.1	234.8	102.1	$Y= -2.4594X + 280.68$	0.52	0.0003	24.52
HEMI	73.5	75.6	69.7	86.6	43.3	$Y = -0.24X2 + 1.11X + 68.64$	0.35	0.0370	24.84
LIGI	34.9	47.2	52.8	85.3	50.7	$Y = -0.0324X^2 + 2.372X + 29.47$	0.51	0.0036	28.58

DMI: intake of dry matter; OMI: intake of organic matter; MMI: intake of mineral material; CPI: intake of crude protein; EEI: intake of ether extract; NDFI: intake of neutral detergent fiber; ADFI: intake of acid detergent fiber; CELI: intake of cellulose; HEMI: intake of hemicellulose; LIGI: intake of lignin; RE: regression equation; R²: coefficient of determination; CV: coefficient of variation.

Another factor that probably negatively influenced the DMI was the high lignin content of diets with the inclusion of the by-product, which, along with the fiber found in diets with higher replacement levels, might have triggered physical-chemical mechanisms that interfered directly with intake. Costa et al. (2010) evaluated the intake and digestibility of diets with different levels of palm oil cake in sheep and observed lignin increase from 7.1% to 14.3%, at 10% and 40% of palm oil cake, respectively, similar to responses found in the present study.

The OMI also presented a negative linear effect. Replacement of 1% of grass by cake led to a reduction in intake of 4.31 g·day^{-1} of OM, and displayed an undesirable effect for this nutrient. The low intake of OM, at the highest replacement levels, followed the effect observed with DMI and the reasons for this occurrence are identical. Likewise, the MMI displayed a negative linear effect related to the replacement levels of grass by murumuru cake. The lowest content was obtained with MC60, with an average intake of 11.4 ± 1.7 g·day^{-1} according to the equation $Y = -0.630X + 52.18$. This may have occurred as a result of the physiological maturation of the murumuru fruit, which, coupled with the increase in the weight of the nut, reduces the concentration of water inside the fruit. This leads to a higher percentage of minerals, causing an elevation of OM and a decrease in MM. Therefore, because the cake is obtained after milling of nuts to acquire oil, the linear decrease in MM intake at a replacement of 0% to 60% is within the normal range.

There was a quadratic effect from the levels of murumuru cake on the EEI. After processing the data, we obtained an optimum level of replacement of 39.95%, with a maximum intake of 223.01 g·day^{-1}, an important finding to avoid underutilization or waste in the nutritional management of the diet. This result indicates that a 39.95% replacement of Mombasa grass by murumuru cake will result in a decrease in EE intake. This is probably because the content of EE in the murumuru cake, 16.32%, and its inclusion in the diet at maximum replacement levels (40% and 60%), of 7.60% and 10.51%, resulted in EE levels considered toxic to the ruminal microbial flora, around 7% in the total dietary DM

(MAIA, 2006). Aferri (2005) states that high levels of unsaturated vegetable oils in animal feed may harm the ruminal balance and reduce the activity of cellulolytic microorganisms, mainly because of the reduction in ruminal pH and toxic effects of long-chain fatty acids on the ruminal bacteria, especially the cellulolytic bacteria. The MC0 showed the lowest values of EE intake (11.0 ± 1.0 $g \cdot day^{-1}$) because the level of EE in grass is low, around 2%.

The CPI presented a negative linear effect, which indicates that as grass was replaced by murumuru cake in the diet, from 0% to 60%, the intake of this nutrient decreased, with mean values, respectively, of 58.3 ± 5.2 g and 25.4 ± 3.7 g CP/day. The regression analysis indicates that, for each 1% replacement by murumuru cake, there was a reduction of 0.46 g of CP intake/day. This may be related to reduced intake of DM in the diets, considering that the CP values in grass and cake are similar.

The NDFI also presented a negative linear effect, demonstrating that, with each 1% of replacement, there was a reduction of 2.43 g of intake of this fibrous fraction. The lowest content was obtained with MC60, with an average intake of 196.1 ± 28.6 $g \cdot day^{-1}$, following the equation $Y = -2.426X + 403.64$. In this treatment, the percentage of NDF was 75.22%, well above the level found with MC0 of 62.20%. The NDF is a fraction of structural carbohydrates of the feed and is related to the adjustment of intake, the rate of passage, and chewing activity of ruminants (CARDOSO et al., 2006). Thus, high levels of NDF in the diet may limit the DMI, but induce higher NDFI (DANTAS FILHO et al., 2007), and this second effect was not observed in the present study.

Although the grass and cake have similarities regarding origin, this difference in intake can be attributed to the nature of the fiber in each. Considering only the NDF content, the concept recommended by the NRC (1985) cannot be applied to the diets studied, especially because murumuru cake is an agroindustrial by-product, probably with a different composition and structure than grass fiber. According to the NRC (2001), when the mean particle size of the forage is less than 3 mm, the NDF in the diet should increase to stimulate chewing and salivary flow of the ruminant. The particle size of the murumuru cake is lower than grass, which reduces the chewing time for the ruminant, with a reduction in the production of saliva and a rise the ruminal pH. One can observe, then, that the variation of the NDFI seems to be influenced by the proportion of each component of the cell wall, which can change the digestibility, and consequently, affect the intake of this nutrient. This may explain the lower intake of NDF in the feed with 60% replacement.

The ADFI displayed a negative linear effect, and indicated that 1% replacement reduces the ADFI by 2.05 g. The lowest content was obtained with MC60, with an average intake of 152.8 ± 22.3 $g \cdot day^{-1}$, following the equation $Y = -2.055X + 324.33$. Foods with a high fiber content, such as murumuru cake, can decrease the DMI because, generally, they are of low digestibility and reduce the physical capacity of the rumen. The ingested food must be removed from the rumen via fermentation or passage to give space for additional intake, which may have caused the lower ADFI observed in this work, similar to the DMI.

The CELI also displayed a negative linear effect, with a reduction of 2.45 g for each 1% of murumuru cake included, and lower intake for MC60 (102.1 ± 14.9 $g \cdot day^{-1}$). This finding is in line with the intake effects of other fibrous components of the diets with higher replacement levels. The HEMI ($g \cdot day^{-1}$) showed a quadratic effect, with an optimum replacement level of Mombasa grass by murumuru cake, according to the regression analysis, of 23.13% and 81.47 $g \cdot day^{-1}$. The diet with murumuru cake raised the HEMI at replacement levels of 0% to 40%, with an intake of 73.5 ± 6.6 g to 86.6 ± 22.0 g, and reduced intake at the 60% replacement level to 43.3 + 6.3 g, probably caused by the reduction in DMI.

The LIGI presented a quadratic effect in which the murumuru cake raised LIGI at levels ranging from 0% to 40%, with an intake of 34.9 ± 3.1 g to 85.3 ± 21.6 g. A large reduction occurred at the 60% replacement level (50.7 ± 7.4 g) owing to the reduction in the DMI. This was probably related to the higher inclusion of lignin in the diets, with the replacement by murumuru cake (28.59%) to the detriment of the grass (5.72%). Contrary to other nutrients, it is desirable that LIGI is not high because of its antinutritional characteristic. According to the regression analysis, estimation of the maximum LIGI related to replacement levels by murumuru cake is 36.60% and 72.88 g of ingestion. Souza Junior et al. (2011) and Bringel et al. (2011) observed the same effect when testing foods with high levels of lignin, using coconut and palm oil cake, respectively, as supplementation for sheep diets.

According to Van Soest (1994), when intake decreases, the feed remains for a longer period within the rumen and, therefore, is more degraded. This occurs through a compensatory effect found with lower passage rates. In these situations, there is higher utilization of food by ruminal microorganisms, thus better digestibility coefficients of nutrients. This result was observed in the present study, with a significant effect ($P < 0.05$) on the apparent digestibility coefficients of all nutritional components evaluated when replacing Mombasa grass by murumuru cake. However, the coefficient of digestibility of crude protein (CDCP) was not significantly different with the diets tested, which ranged from 63.0% to 65.1% (Table 3).

Table 3. Coefficient of digestibility in sheep fed diets with different replacement levels of Mombasa grass (*P. maximum* cv. Mombasa*)* by murumuru cake (*A. murumuru* var. murumuru, Mart.).

Variable (%)	Replacement level by murumuru cake					RE	R^2	P	CV (%)
	0%	10%	20%	40%	60%				
CDDM	60.0	60.8	63.3	64.8	63.5	$Y = 0.067X + 60.71$	0.24	0.0280	4.32
CDOM	63.1	64.2	66.4	67.3	65.8	$Y = 0.225X + 62.85$	0.27	0.0435	4.04
CDCP	64.7	65.1	63.4	63.0	63.0	$Y = 63.84$	-	0.42	6.42
CDEE	64.7	68.9	78.5	87.6	88.1	$Y = -0.0079X^2 + 0.089X + 63.28$	0.88	0.0033	4.79
CDNDF	58.5	62.3	66.1	67.7	66.7	$Y = -0.005X^2 + 0.451X + 58.57$	0.62	0.0082	4.44
CDADF	56.1	65.5	65.4	64.6	60.2	$Y = -0.009X^2 + 0.564X + 57.88$	0.47	0.0013	6.00
CDCEL	61.2	71.7	71.9	68.1	60.2	$Y = -0.012X^2 + 0.659X + 63.24$	0.62	0.0001	5.90
CDHEM	68.3	49.4	68.7	79.4	89.4	$Y = 0.504X + 57.94$	0.55	0.0002	14.48

MC: murumuru cake; CDDM: coefficient of digestibility of dry matter; CDOM: coefficient of digestibility of organic matter; CDCP: coefficient of digestibility of crude protein; CDEE: coefficient of digestibility of ether extract; CDNDF: coefficient of digestibility of neutral detergent fiber; CDADF: coefficient of digestibility of acid detergent fiber; CDCEL: coefficient of digestibility of cellulose; CDHEM: coefficient of digestibility of hemicellulose; RE: regression equation; R^2: coefficient of determination; CV: coefficient of variation.

The CDDM displayed a positive linear effect. For each 1% replacement with murumuru cake, there was a 0.067% increase in CDDM. Similar results were observed with the CDOM, with an increasing linear effect from 0% to 60% replacement. For each 1% replacement with murumuru cake, the CDOM increased by 0.225%.

The CDEE also displayed a quadratic effect. The highest CDEE levels were found with MC40 and MC60, respectively, 87.6 ± 2.2% and 88.1 ± 2.0%. Using regression analysis, the optimum level of murumuru cake for the variable CDEE was

56.65% replacement, with a maximum digestibility of 88.63%. Thus, CDEE is at a maximum at 56.65% of murumuru cake replacement, and the content of EE is about 10%. From this replacement level, the CDEE drops dramatically. These results indicate that the lipid fraction of murumuru cake is highly digestible, because, according to Maia (2006), EE values above 7% are considered toxic to the ruminal microbial flora and can impair the ruminal balance, in addition to affecting the activity of cellulolytic microorganisms, mainly because of a reduction in ruminal pH.

The CDNDF presented a quadratic effect, and an optimum replacement level of 41% was obtained, with a digestibility of 67.82%. The lowest content was found with MC0, with an average intake of 58.5 ± 2.0%, following the equation $Y = -0.005X^2 + 0.451X + 58.57$. CDADF also presented a quadratic effect. The mean CDADF values ranged from 56.1 ± 2.3 to 65.5 ± 1.2%, with an optimum level of 31.33% replacement and maximum apparent digestibility of 66.72%. An increase in the content of ADF occurred at the maximum replacement level by murumuru cake. This possibly led to a high accumulation of non-digestible fibrous residues in the rumen, mainly lignin, a component of ADF, which resulted in a reduction in digestibility (MINSON, 1990) and, consequently, a lower passage rate of food with losses in intake by sheep.

The CDCEL presented a quadratic effect and, according to the derived equation, a maximum CDCEL of 72.29% was obtained at a replacement level of 27.46%. These results are similar to those of Teixeira and Borges (2005), who observed the same quadratic effect when assessing the effect of replacement of oil extraction by-products for sheep. The CDHEM showed a positive linear effect and indicated that each 1% of replacement increased the CDHEM by 0.504%. The highest digestibility occurred with the MC40 and MC60 diets, 79.4 ± 2.9 and 89.4 ± 2.6%, respectively, according to the equation $Y = 0.504X + 57.94$. The hemicellulose in murumuru cake is possibly more digestible than that of the Mombasa grass. The manner in which the digestibility of hemicellulose responded to the increase of cake in the diet can be explained by its higher susceptibility to acid hydrolysis in the abomasum and duodenum, which releases acetyl groups and esterified hydroxy cinnamic acid, making it more digestible in the lower digestive tract (MERCHEN; BOURQUIN, 1994).

The determination of nitrogen balance, i.e., the nitrogen consumed minus the fecal and urinary nitrogen, under controlled conditions, quantifies the proteic metabolism and shows, specifically, if the body is gaining or losing protein (LADEIRA et al., 2002). In the present study, regression analysis showed a negative linear response ($P < 0.05$) in the nitrogen balance due to the inclusion of murumuru cake in the diets (Table 4). For each 1% replacement of the cake for Mombasa grass, a reduction occurred in the nitrogen balance of 0.034 $g \cdot day^{-1}$. Nitrogen balance followed the negative linear response of DMI. Nitrogen balance was lower in animals fed a diet containing 60% murumuru cake (2.3 ± 0.6 g), probably because of lower intake of CP.

Table 4. Nitrogen balance (NB) in diets with different replacement levels of Mombasa grass by murumuru cake (MC0, MC10, MC20, MC40, and MC60), with the respective regression equations (RE), coefficients of determination (R^2), and coefficients of variation (CV).

Variable (g/day)	Replacement level by murumuru cake					RE	R²	P	CV%
	MC0	MC10	MC20	MC40	MC60				
N-ingested	9.2	8.9	7.8	8.6	4.2	Y = -0.070X + 9.56	0.41	0.0024	24.74
N-fecal	2.9	2.8	2.6	3.0	1.3	Y = -0.022X + 3.11	0.31	0.0100	28.52
N-absorbed	1.5	1.2	0.9	0.9	0.5	Y = -0.048X + 6.45	0.39	0.0031	26.32
N-retained	6.2	6.0	5.2	5.6	2.9	Y = 53.01	-	0.29	51.01
N-balance	4.7	4.9	4.3	4.7	2.3	Y = -0.034X + 5.06	0.28	0.017	29.73

MC: murumuru cake; RE: regression equation; R²: coefficient of determination; CV: coefficient of variation. N-absorbed = (N Supplied - N Leftover) - N Feces; N-retained = (N Supplied - N Leftover) - (N Feces + N Urine); N-balance = N ingested - N fecal N urinary (SILVA; LEÃO, 1979).

Intake of nitrogen exceeded its excretion, which demonstrated that the animals receiving increasing replacement levels of murumuru cake were in positive nitrogen balance. In turn, this indicated that protein requirements were fulfilled, despite the reduction in intake of nitrogen at the 60% replacement level.

A lower nitrogen retention was observed at the 60% replacement level, with 2.9 ± 0.4 $g \cdot day^{-1}$. This can be attributed to the lower use of dietary nitrogen by animals, given that there was a lower intake of nitrogen in this group. Thus, nitrogen balance is an important tool for determining the efficiency of nitrogen use by ruminants and their losses to the environment (GENTIL et al., 2007).

Conclusion

Murumuru cake, an agroindustry cosmetic by-product, is an alternative to Mombasa grass as a dietary supplement in ruminants because it increases nutrient digestibility in sheep. However, a limited replacement level must be implemented, considering that, when using 27.46%, 31.33%, 41%, and 56,65% replacement, a decline occurs in the digestibility of cellulose fiber, acid detergent fiber, neutral detergent extract, and ether extract, respectively, although a negative nitrogen balance does not occur. It is important to highlight that the use of this alternative ingredient in ruminant diets can prevent its disposal and accumulation in the environment.

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