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Nutritional value of babassu cake as a replacement for roughage in sheep feed[1]

Valor nutritivo da torta de babaçu em substituição ao volumoso na alimentação de ovinos

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ABSTRACT - The use of agro-industrial by-products in feeding ruminants has nutritional, environmental and economic advantages, and helps to sustain the production system. The aim of this study was to evaluate the nutritional value of diets containing babassu cake as a substitute for Tifton-85 hay (70, 140, 210, 280 and 350 g kg^{-1} dry matter: DM). Twenty-five castrated male sheep with a mean body weight of 49.6 ± 9.4 kg were used, distributed in metabolic cages in a completely randomised design. Voluntary intake was obtained from the difference between the amount of feed provided and the leftovers the following morning. To evaluate nutrient digestibility and nitrogen (N) balance, samples of urine and faeces were collected separately. There was no effect on DM intake; however, crude protein (CP) and ether extract intake increased linearly increased linearly. The addition of babassu cake had no effect on DM digestibility (mean value of 604.6 ± 272.8 g kg^{-1}). Apparent CP digestibility and total digestible nutrient content showed increasing linear behaviour, while the digestibility of acid detergent fibre decreased linearly. The level of retained N varied from 9.72 ± 1.12 to 15.51 ± 1.84 g day^{-1} with the ratio to ingested N ranging from 521.0 ± 26.7 to 578.4 ± 31.8 g kg^{-1} N. The addition of babassu cake to replace the roughage, increased the nutritional value of the diet. Babassu cake can be included up to a total of 350 g kg^{-1} DM in the diet as a substitute for Tifton-85 hay.

Key words: Alternative feed. Nitrogen balance. Coefficient of digestibility. Intake. Agro-industrial by-product.

RESUMO - A utilização de subprodutos agroindustriais na alimentação de ruminantes apresenta vantagens nutricionais, ambientais e econômicas, contribuindo para a sustentabilidade do sistema de produção. Assim, objetivou-se avaliar o valor nutritivo de dietas contendo torta de babaçu em substituição ao feno de Tifton-85 (70; 140; 210; 280 e 350 g kg^{-1} de matéria seca; MS). Foram utilizados 25 ovinos machos castrados, com peso corporal médio de 49,6 ± 9,4 kg, alocados em gaiolas metabólicas em delineamento inteiramente casualizado. O consumo voluntário foi obtido pela subtração da quantidade de alimento fornecido pela sobra pesada na manhã seguinte. Para avaliação da digestibilidade dos nutrientes e balanço de nitrogênio (N), amostras de urina e fezes foram coletadas separadamente. O consumo de MS não foi influenciado, contudo o consumo de proteína bruta (PB) e extrato etéreo aumentaram linearmente. A inclusão da torta de babaçu não afetou a digestibilidade da MS (média de 604,6 ± 272,8 g kg^{-1}). A digestibilidade aparente da PB e os teores de nutrientes digestíveis totais apresentaram comportamento linear crescente, enquanto a digestibilidade da fibra em detergente ácido decresceu linearmente. O teor de N retido variou de 9,72 ± 1,12 a 15,51 ± 1,84 g dia^{-1} e sua relação com o N ingerido variou entre 521,0 ± 26,7 e 578,4 ± 31,8 g kg^{-1} de N. A inclusão da torta de babaçu, em substituição ao volumoso, incrementou o valor nutritivo da dieta, podendo ser incluída em até 350 g kg^{-1} da MS na dieta, em substituição ao feno de Tifton-85.

Palavras-chave: Alimentos alternativos. Balanço de Nitrogênio. Coeficiente de digestibilidade. Consumo. Subproduto agroindustrial.

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INTRODUCTION

Inadequate nutrition, aggravated by the seasonal availability of forage, is an important factor that limits the productive and reproductive efficiency of ruminants, and is considered one of the biggest barriers to livestock production (DETMANN *et al*., 2014). In the Northeast, adverse climate conditions, together with poor nutritional, reproductive and health management, hamper the development of agriculture and livestock farming (LOUSADA JÚNIOR *et al*., 2005).

The use of agro-industrial by-products in feeding ruminants has several advantages, such as reducing the dependence of these animals on cereals that can be used for human consumption, reducing environmental pollution, transforming products that are unsuitable for human consumption into products of high biological value for livestock, and decreasing feeding costs (CARRERA *et al*., 2012; OLIVEIRA *et al*., 2013). To be economically attractive, one of the necessary characteristics for the by-product is low nutrient cost per unit of dry matter, justifying its addition to the diet through a reduction in the cost of feeding the animals (BRINGEL *et al*., 2011).

According to Abdalla *et al*. (2008), the cake and meal obtained from agro-industry have the proper nutritional characteristics for use in ruminant diets. However, the authors point out that attention should be paid to possible problems caused by the presence of antinutritional bioactive factors in some materials, requiring careful study before the safe introduction of these materials as ingredients in animal feed.

Among the by-products available for animal feed, there are those from the production of babassu oil - *Orbygnia* sp. (ABDALLA *et al*., 2008; OLIVEIRA *et al*., 2012). Two different products originate from the extraction of babassu oil, which depend on the process used by the industry: babassu cake, resulting from the pressing process, and babassu meal, derived from the process that uses chemical solvent (SÁ *et al*., 2015b). Both are potential feed for different species and categories of animals.

Due to its physical and chemical characteristics, babassu cake has the potential for use as an alternative source of both energy and protein in ruminant diets, thereby replacing more noble grains, such as maize and soya, used in feeding humans and non-ruminants (FERREIRA *et al*., 2011). However, despite being widely used by producers of animal feed, especially in the north and northeast of Brazil, few studies have been developed to evaluate the nutritional value of this food, highlighting the work of Sá *et al*. (2015a).

In this context, the aim was to evaluate voluntary intake, the coefficient of digestibility and nitrogen balance in sheep diets containing increasing levels of babassu cake used as a substitute for Tifton-85 hay (*Cynodon* sp.).

MATERIAL AND METHODS

The experiments and laboratory analysis were respectively carried out at the School of Veterinary Medicine and Animal Science (EMVZ) of the Federal University of Tocantins (UFT), in Araguaína, Tocantins, and the Animal Metabolism and Calorimetry Laboratory of the Department of Animal Science, at the UFMG Veterinary School, in Belo Horizonte, Minas Gerais.

For the treatments, five levels of babassu cake were added to the diets as a substitute for the Tifton-85 hay (70, 140, 210, 280 and 350 g kg^{-1} DM). The babassu cake used was obtained through the mechanical extraction of almond oil.

Twenty-five castrated, male sheep of indeterminate breed were used, with a mean body weight of 49.6 ± 9.4 kg and approximately 18 months of age. The animals were first trimmed and weighed. After weighing, they were identified and dewormed, given ADE vitamin complex, and then individually housed in metabolic cages.

The cages were made of iron, and were 1.50 m long and 0.80 m wide, with slatted-wooden floors and side screens, stainless steel feeders and plastic salt and drinking troughs. The room and the cages were cleaned daily before offering the feed, and the faeces were removed by sweeping. Once a week the room and cages were washed with water.

The animals were distributed in a completely randomised design with five treatments and five replications. The experiment lasted 26 days, with 21 days to adapt to the diets, management and facilities, and five days for the experimental collections.

The feed was offered in the form of a complete mixture twice a day (07:00 and 17:00 h), calculated to be consumed at will (between 90 and 100 g DM $kg^{-0.75}$). The amount given was adjusted to allow for leftovers of between 10 and 15%. Water and a mineral mixture recommended for sheep was available at all times. Tifton-85 hay (*Cynodon* spp.), chopped in a forage machine, was used as roughage.

The babassu cake was mixed with ground maize at a ratio of 7 to 3. Maize was included to increase diet acceptance by the animals. At first, there was a gradual attempt to replace the roughage with babassu cake only, but this was not consumed by the animals. Therefore, maize was gradually added in order to increase acceptability, starting with one part maize for nine parts babassu cake. The amount of maize was increased until the animals started to consume the diet, reaching seven parts babassu cake for three parts ground maize (Tables 1 and 2). In formulating the diets, the values for total digestible nutrients (TDN) as described in the Brazilian Feed Composition Tables for Ruminants were used (VALADARES FILHO *et al*., 2015).

During the five days of collections, samples of the feed offered, the respective individual leftovers, faeces and urine were taken each morning.

Of the feed offered, around 300 g was collected per day. All the leftovers were weighed and stored. Urine and faeces were collected separately in buckets and trays positioned below the cages. One hundred mL HCl_2N was added to the urine collection buckets each day to prevent nitrogen being lost from the urine. The volume of urine

Table 1 - Chemical composition of the ingredients of the experimental diets

Nutrient (g kg^{-1})	Ingredients		
	Babassu cake	Ground maize	Tifton-85 hay
Dry matter[1]	901.0	849.8	858.8
Crude protein[2]	205.8	105.8	84.8
Neutral detergent fibre[2]	630.6	136.3	778.6
Acid detergent fibre[2]	340.0	37.4	391.4
Hemicellulose[2]	290.6	98.9	387.2
Total carbohydrates[2]	655.1	823.2	839.9
Non-fibrous carbohydrates[2]	24.5	686.9	61.3
Ether extract[2]	94.2	41.0	11.0
Ash[2]	44.9	30.0	64.3

[(1)]g kg^{-1} natural matter; [(2)]g kg^{-1} dry matter

Table 2 - Composition of the experimental diets containing babassu cake as a susbtitute for Tifton-85 hay

Ingredient (g kg^{-1} DM)	Level of substitution (g kg^{-1} DM)				
	70.0	140.0	210.0	280.0	350.0
Babassu cake	70.0	140.0	210.0	280.0	350.0
Ground maize	30.0	60.0	90.0	120.0	150.0
Tifton-85 hay	900.0	800.0	700.0	600.0	500.0
	Chemical composition				
Nutrient (g kg^{-1})					
Dry matter[1]	861.2	863.5	865.8	868.1	870.5
Organic matter[2]	937.4	939.1	940.8	942.5	944.1
Crude protein[2]	94.9	105.1	115.2	125.3	135.5
Neutral detergent fibre[2]	750.4	722.1	693.9	665.6	637.4
Acid detergent fibre[2]	375.8	360.2	344.6	329.0	313.4
Hemicellulose[2]	374.6	361.9	349.3	336.6	324.0
Total carbohydrates[2]	824.8	809.6	794.4	779.3	764.1
Non-fibrous carbohydrates[2]	74.4	87.5	100.6	113.7	126.7
Ether extract	17.7	24.4	31.2	37.9	44.6
Ash[2]	62.6	60.9	59.2	57.5	55.9

[(1)]g kg^{-1} natural matter; [(2)]g kg^{-1} dry matter was measured each morning, and an aliquot of 10% of the total was collected. The faeces were removed and weighed, and samples corresponding to 20% of the total were taken. All the samples were stored in a cold chamber (-5ºC).

At the end of the collection period, the samples were homogenised to prepare composite samples of the feed, leftovers, faeces and urine. The samples were duly identified and frozen (-10 to -15 ºC) for later laboratory analysis.

The samples of feed, leftovers and faeces were pre-dried in a forced ventilation oven (55 ºC for 72 hours) and then ground in a Wiley mill with a 1mm mesh sieve, and stored in lidded polyethylene bottles.

The samples of feed offered, leftovers and faeces were analysed in duplicate. The DM content was determined in an oven at 105 ºC, the crude protein (CP) was determined from the total nitrogen content by the Kjeldahl method (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1995), and the ether extract (EE) and ash content were determined as per Silva and Queiroz (2002).

The neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analysed following the sequential method of Van Soest, Robertson and Lewis (1991), with the addition of thermo-resistant amylase in the ANKOM Fibre Analyser. The urine samples were analysed to determine total nitrogen following the same Kjeldahl method used for CP (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1995). The hemicellulose content was considered equal to the difference between the concentrations of NDF and ADF. Total carbohydrates (TC), non-fibrous carbohydrates (NFC) and total digestible nutrients (TDN) were estimated using the equations proposed by Sniffen *et al*. (1992).

Nutrient intake from the diets was determined from the difference between the amount of a given nutrient in the feed offered to the animals and the leftover amount of the same nutrient in the trough.

The intake of dry matter, organic matter, crude protein, ether extract, neutral detergent fibre, acid detergent fibre, total carbohydrates and total digestible nutrients were determined, in grams per day (g day^{-1}), percentage of body weight (%BW) and grams per unit of metabolic size (g kg$^{-0.75}$).

The coefficient of digestibility (CD) was calculated for the different nutrients as per equation 1.

$$CD(\%) = [(IN(g)-NEF(g))/IN(g)]x100 \quad (1)$$

where: IN = ingested nutrient (g) and NEF = nutrient excreted in the faeces (g).

The nitrogen balance (NB) was also determined, giving the absorbed nitrogen (AN g day^{-1}) and the retained nitrogen (RN g day^{-1} and g kg$^{-0.75}$), as well as the ratio of retained nitrogen to ingested nitrogen as a percentage (RN/IN). To calculate the AN and RN, the values of ingested nitrogen (IN), faecal nitrogen (FN) and urine nitrogen (UN) were used, as per equations 2 and 3.

$$AN = IN-FN \quad (2)$$

$$RN = IN-(FN+UN) \quad (3)$$

Regression analysis was carried out to evaluate the effect of the added levels of babassu cake. In the regression analysis, the choice of the most appropriate model for each variable was based on the significance of the linear, quadratic and cubic coefficients at a significance level of 0.05, using the SAS computer software (SAS INSTITUTE, 2003). Assumptions of normal distribution and homoscedasticity of the data were verified before carrying out the analysis.

RESULTS AND DISCUSSION

Dry matter (DMI) and organic matter (OMI) intake in g day^{-1}, %BW and g kg$^{-0.75}$ were not influenced by the addition of babassu cake to the diets (P>0.05; Table 3). Sá *et al*. (2015a), working with different levels of babassu cake in sheep diets (0, 75, 150 and 250 g kg^{-1}), also found no effect on DMI, which, according to these authors, shows the possibility of including babassu cake in sheep diets without any major restrictions.

This behaviour differed from that seen by Xenofonte *et al*. (2008), who obtained a cubic response for DMI, expressed both in %BW and g kg$^{-0.75}$, in a study with another by-product of the babassu. These authors worked with four added levels (0, 100, 200 and 300 g kg^{-1} DM) of babassu meal in the diet of mixed-breed lambs, with a reduction seen in the values for DMI as the babassu meal was added to the diet.

Miotto *et al*. (2012) evaluated sheep diets with 0, 210, 380, 620 and 780 g kg^{-1} of babassu mesocarp meal replacing elephant grass silage and found no effect on DMI or OMI. However, Sá *et al*. (2015b) saw a linear reduction in DMI for different levels of babassu endocarp bran added to sheep diet, showing that by-products of the babassu could have the characteristics of dietary roughage. This was not seen in the present study, probably due to the dietary roughage having been substituted.

Bringel *et al*. (2011) found a quadratic response for all the variables of intake and digestibility under

Table 3 - Intake of dry matter (DM), organic matter, crude protein and ether extract in sheep fed babassu cake as a substitute for Tifton-85 hay

Variable	Level of substitution (g kg^{-1} DM)					Equation	R^2	CV (%)
	70	140	210	280	350			
Dry matter intake								
g day^{-1} [(1)]	1177.34	1148.82	1192.38	1206.10	1247.69	$\tilde{Y}$= 1194.47 ± 225.46[ns]	-	18.83
%BW[(2)]	2.29	2.22	2.52	2.63	2.38	$\tilde{Y}$=2.41 ± 0.38[ns]	-	15.25
g $kg^{-0.75}$ [(3)]	61.14	59.53	65.92	68.39	63.95	$\tilde{Y}$= 63.79 ± 9.37[ns]	-	15.46
Organic matter intake								
g day^{-1}	1105.82	1081.25	1123.75	1137.16	1176.54	$\tilde{Y}$=1124.91 ± 212.56[ns]	-	15.85
%BW	2.15	2.09	2.37	2.48	2.24	$\tilde{Y}$=2.27 ± 0.36[ns]	-	15.29
g $kg^{-0.75}$	57.42	56.02	62.13	64.48	60.31	$\tilde{Y}$=60.08 ± 8.85[ns]	-	15.46
Crude protein intake								
g day^{-1}	116.61	122.19	139.26	151.23	168.02	$\hat{Y}$=99.9082 + 1.8838X*	34.60	19.16
%BW	0.22	0.23	0.29	0.32	0.32	$\hat{Y}$=0.1976 + 0.004X*	45.83	15.93
Ether extract intake								
g day^{-1}	21.65	28.73	36.76	46.73	57.71	$\hat{Y}$= 11.288 + 1.28726X*	82.38	16.03
%BW	0.04	0.05	0.07	0.10	0.11	$\hat{Y}$=0.0234 + 0.0026X*	87.17	13.20

[(1)]grams per day; [(2)]percentage body weight; [(3)]grams per unit of metabolic size per day (g $kg^{-0.75}$); *P<0.01; ns = P>0.05

evaluation at different levels of palm cake (0, 200, 400, 600 and 800 g kg^{-1}) as a substitute for elephant grass silage, suggesting a maximum level of 373.4 g kg^{-1} for this by-product. This may have been due to differences in the digestibility of the fibrous fraction between the palm cake and the babassu cake, which would limit the addition of palm cake in the diets.

The DMI (g $kg^{-0.75}$) obtained at the maximum added level (350 g kg^{-1} DM) in the present study was 15.7% greater than that seen by Xenofonte *et al*. (2008), in a diet including 300 g kg^{-1} of babassu bran DM, and similar to that obtained by Sá *et al*. (2015a) at an added level of 250 g kg^{-1} (69 g $kg^{-0.75}$).

It should be noted that the observed coefficients of variation (Table 3) were all less than 20%, the value usually found in studies of sheep intake.

According to the National Research Council (2007), the minimum DMI required to maintain adult sheep is 53.19 g $kg^{-0.75}$, which is lower than the smallest mean value obtained in the present study, of 59.53 ± 9.37 g $kg^{-0.75}$ for the diet including 140 g kg^{-1} of babassu cake DM.

The responses for crude protein (CPI) and ether extract (EEI) intake were linear (P<0.05), and can be explained by the greater content of these nutrients in diets with higher added levels of babassu cake. The CPI increased by 1.88 g day^{-1} for every 10 g of babassu cake added to the diet (P<0.05).

The EE content of the babassu cake used in the trial was approximately 8.6 times the content of the same nutrient in the Tifton-85 hay (Table 1), which resulted in greater amounts of EE in the diets as the addition of babassu cake increased (Table 2). The response for EE intake, in g day^{-1} and in %BW, was linear, where for each 10 g of babassu cake added to the diet, the EEI increased by 1.29 g day^{-1} (P<0.05). The intake of high levels of EE may have a negative effect on the DMI, as it hampers the digestion of fibre, a fact that has not been verified. Abdalla *et al*. (2008), pointed out that the use of feed with high levels of EE, such as babassu cake, in the diet of ruminants could be helpful in reducing methane production.

Intake of the fibrous fractions (NDF and ADF) was not influenced by the diets, nor was the intake of TC (Table 4). It was expected that reductions in the levels of NDF and ADF in the diets with the addition of babassu cake (Table 2), as well as the lack of statistical significance (P>0.05) for DMI, would reduce the intake of these components, however, this was not seen in the present study.

Sheep are animals with a great capacity for food selection, and it was seen in this trial, that the animals which received diets with higher levels of babassu cake and consequently less hay, consumed more roughage, since the diet was offered as a complete mixture and the leftovers collected in the troughs contained proportionally greater amounts of babassu cake than of hay. Such

Table 4 - Intake of neutral detergent fibre, acid detergent fibre, total carbohydrates and total digestible nutrients in sheep fed babassu cake as a substitute for Tifton-85 hay

Variable	Level of substitution (g kg^{-1} DM)					CV(%)
	70	140	210	280	350	
Neutral detergent fibre intake						
g $day^{-1(1,4)}$	875.37	829.67	824.52	803.50	800.45	15.89
%BW$^{(2,5)}$	1.70	1.60	1.74	1.75	1.52	15.37
g $kg^{-0.75(3,6)}$	45.45	42.97	45.63	45.60	40.99	15.52
Acid detergent fibre intake						
g $day^{-1(7)}$	439.46	415.98	412.51	399.82	398.14	15.82
%BW$^{(8)}$	0.85	0.80	0.87	0.87	0.76	15.36
g $kg^{-0.75(9)}$	22.81	21.53	22.84	22.70	20.38	15.45
Total carbohydrate intake						
g $day^{-1(10)}$	967.55	930.33	947.73	939.20	950.80	16.15
%BW$^{(11)}$	1.89	1.80	2.01	2.05	1.82	15.56
g $kg^{-0.75(12)}$	50.24	48.19	52.41	53.28	48.73	15.73
Total digestible nutrient intake						
g $day^{-1(13)}$	707.92	698.32	751.22	769.66	815.02	16.46
%BW$^{(14)}$	1.37	1.36	1.60	1.68	1.55	15.72
g $kg^{-0.75(15)}$	36.59	36.23	41.73	43.62	41.67	16.00

$^{(1)}$grams per day; $^{(2)}$percentage body weight; $^{(3)}$grams per unit of metabolic size per day (g $kg^{-0.75}$); $^{(4)}\tilde{Y}$=826. 91 ± 158. 34 ^{ns}; $^{(5)}\tilde{Y}$=1. 67 ± 0. 26^{ns}; $^{(6)}\tilde{Y}$=44. 13 ± 6. 39^{ns}; $^{(7)}\tilde{Y}$=413. 19 ± 79. 43^{ns}; $^{(8)}\tilde{Y}$=0. 83 ± 0. 13^{ns}; $^{(9)}\tilde{Y}$=22. 06 ± 3. 19 ^{ns}; $^{(10)}\tilde{Y}$=947. 12 ± 180. 03^{ns}; $^{(11)}\tilde{Y}$=1. 91 ± 0. 30^{ns}; $^{(12)}\tilde{Y}$=50. 57 ± 7. 38^{ns}; $^{(13)}\tilde{Y}$= 748. 43 ± 150. 27^{ns}; $^{(14)}\tilde{Y}$=1. 51 ± 0. 26^{ns}; $^{(15)}\tilde{Y}$=39. 97 ± 6. 46^{ns}; ^{ns} = P>0. 05

selective behaviour may have occurred with the aim of increasing the intake of longer fibres, or due to the cake being less palatable compared to the Tifton-85 hay. Therefore, despite the addition of babassu cake causing a reduction in the levels of NDF and ADF, the selection of roughage feed made by the animals allowed them to consume similar amounts of these nutrients, as was also seen by Miotto *et al*. (2012).

There was no effect from the addition of babassu cake on the TDNI (P>0.05), which ranged from 36.23 ± 4.82 to 43.62 ± 6.46 g $kg^{-0.75}$, with a mean value of 15.1 g kg^{-1} body weight. This result shows that the addition of this feed to the sheep diet allowed similar energy intake to that seen in diets containing higher levels of Tifton-85 hay, roughage considered to be of good quality, suggesting that babassu cake might be nutritionally viable in sheep.

Apparent dry matter digestibility (DMD) and apparent organic matter digestibility (OMD) were not influenced (P>0.05) by the addition of babassu cake to the diets (Table 5). According to Pulina *et al*. (2013), the observed values for DMD can be considered high (>60.0%), suggesting the prevalence of metabolic DMI control mechanisms.

Xenofonte *et al*. (2008), obtained a linear response for both DMD and OMD, with respective values of up to 68.4 and 70.9% in the diet with 300.0 g kg^{-1} babassu cake DM. The above authors explained that the reduction in DM and OM intake may have resulted in greater digestibility due to the longer time the material remains in the gastrointestinal tract.

Miotto *et al*. (2012), evaluating apparent digestibility in sheep receiving diets with different levels of babassu mesocarp meal (0, 210, 380, 620 and 780 g kg^{-1} DM) as a substitute for elephant grass silage, found quadratic behaviour for DMD, and that the substitution of 100 g kg^{-1} DM elephant grass silage afforded a maximum digestibility of 52.5%. The mean value for DMD in the present study was greater than each of the mean values obtained by the above authors.

The coefficient of apparent digestibility for crude protein (CPD) and ether extract (EED) were influenced by the addition of babassu cake to the diets (P<0.05). The observed increases in CPD and EED with the addition of babassu cake can be explained by this addition having increased the content of these nutrients in the diets without affecting dry matter intake. As such, the animals ingested

Table 5 - Coefficients of apparent nutrient digestibility (%) in sheep fed diets containing babassu cake as a substitute for Tifton-85 hay

Variable	Level of substitution (g kg-¹ DM)					Equation	R^2	CV (%)
	70	140	210	280	350			
DMD[(1)]	60.01	60.00	60.46	61.50	60.31	$\tilde{Y} = 60.46 \pm 2.72^{ns}$	-	4.96
OMD[(2)]	62.47	62.87	64.22	63.46	63.99	$\tilde{Y} = 63.40 \pm 2.98^{ns}$	-	5.14
CPD[(3)]	63.92	66.42	69.18	71.23	71.87	$\hat{Y} = 62.3096 + 0.29594X^{*}$	56.90	3.88
EED[(4)]	53.02	67.99	76.99	79.70	83.40	$\hat{Y} = 36.05 + 2.8X - 0.042X^{2*}$	83.21	7.17
NDFD[(5)]	67.88	65.12	66.43	63.13	63.12	$\tilde{Y} = 65.13 \pm 4.02^{ns}$	-	6.11
ADFD[(6)]	67.44	64.90	63.84	59.88	58.78	$\hat{Y} = 69.6692 - 0.31909X^{*}$	37.24	6.79
TCD[(7)]	62.50	61.10	62.98	61.38	61.42	$\tilde{Y} = 61.88 \pm 2.97^{ns}$	-	5.20
TDN[9]	59.90	60.43	63.56	63.73	65.16	$\hat{Y} = 58.4052 + 0.1976X^{**}$	36.41	4.31

* = P<0.01; ^{ns} = P>0.05; [1]DMD - apparent dry matter digestibility; [2]OMD – apparent organic matter digestibility; [3]CPD - apparent crude protein digestibility; [4]EED - apparent ether extract digestibility; [5]NDFD - apparent neutral detergent digestibility; [6]ADFD - apparent acid detergent digestibility; [7]TCD - apparent total carbohydrate digestibility; [8]TDN - total digestible nutrients

similar amounts of DM, however consumed more CP and EE in diets with higher levels of babassu cake. Generally, a higher DM intake leads to lower nutrient digestibility, as this is associated with an increase in the passage rate of the digested material.

Evaluating different oilseed cakes (soya, sunflower and peanuts) as a substitute for soybean meal, Santos *et al*. (2014) found no effect on apparent nutrient digestibility, suggesting that these by-products might comprise alternative ingredients for feeding sheep, a fact also suggested for babassu cake by the present study.

The apparent digestibility of neutral detergent fibre (NDFD) and total carbohydrates (TCD) was not affected by the addition of babassu cake to the diets (P>0.05). The mean NDFD was 65.13 ± 4.02%, a value almost twice as high as the mean value found by Xenofonte *et al*. (2008), of 38.6%, and who also saw no effect from babassu bran cake on NDFD in sheep.

The apparent digestibility of acid detergent fibre (ADFD) showed a decreasing linear effect (P<0.05) from the increase in babassu cake in the diets. The ADFD decreased (P<0.05) by 0.32% for every 10 g of babassu cake added to the diet. The increase in the EE content of the diets with the addition of babassu cake, may have affected ruminal digestion of the fibre by inhibiting microbial activity, since according to Nússio, Campos and Lima (2006), high levels of lipids in the feed cause changes in ruminal fermentation patterns, resulting in a negative effect on the microorganisms and a reduction in the digestibility of the fibrous fractions.

The values for TDN increased linearly (P<0.05) with the addition of babassu cake to the diets. This can be explained by the increase in CP and EE digestibility. The TDN at the maximum added level of babassu cake (350 g kg^{-1} DM) was approximately 8.8% higher than that seen at the lowest level (70 g kg^{-1} DM), showing the energy potential of the feed.

For nitrogen balance (NB) in the diets, demonstrated via the retained nitrogen (RN), all the parameters, except faecal nitrogen (FN), showed an increasing linear response (P<0.05) to the addition of babassu cake (Table 6).

Ingested nitrogen (IN) increased by 0.3 g for every 10 g of babassu cake added to the diets (P<0.05), possibly as a result of the increase in CPI. Urine nitrogen also showed an increasing linear response (P<0.05) to the addition of babassu cake to the diets, however, these losses were not enough to reduce the RN. Each diet showed a positive NB (RN), ranging from 9.72 ± 1.12 to 15.51 ± 1.84 g day^{-1}, with an increase of 0.2 grams of retained N for every 10 g of added babassu cake (P<0.05). The proportion of RN relative to IN varied from 521.0 ± 26.7 g and 578.4 ± 31.8 g kg^{-1} N.

Working with different levels of palm cake to substitute elephant grass silage, Bringel *et al*. (2011) found a different response for the NB showing a quadratic effect, with the NB increasing to an added level of 450 g kg^{-1} and then decreasing due to the reduction in CPI.

Studying other agro-industrial by-products, Lousada Júnior *et al*. (2005) evaluated the NB of different fruit processing residues and obtained a lower mean value (5.76 g day^{-1}) than that of the present study, showing the potential of babassu cake compared to other by-products.

Table 6 - Nitrogen balance in sheep fed diets containing babassu cake as a substitute for Tifton-85 hay

Variable	Level of substitution (g kg^{-1} DM)					Equation	r^2	CV (%)
	70	140	210	280	350			
IN, g day^{-1} (1)	18.66	19.55	22.28	24.20	26.88	$\hat{Y}$ = 15.99 + 0.30X**	0.98	20.44
FN, g day^{-1} (2)	6.70	6.51	6.94	6.95	7.54	$\tilde{Y}$ =6.93 ± 0.38^{ns}	-	22.66
UN, g day^{-1} (3)	2.24	2.94	2.69	3.68	3.83	$\hat{Y}$ = 1.90 + 0.06X**	0.85	25.27
AN, g day^{-1} (4)	11.96	13.04	15.34	17.25	19.34	$\hat{Y}$ = 9.70 + 0.27X**	0.99	20.74
RN, g day^{-1} (5)	9.72	10.11	12.65	13.57	15.51	$\hat{Y}$ = 7.80 + 0.21X**	0.96	23.69
RN, g $kg^{-0,75}$ (6)	0.51	0.53	0.70	0.77	0.80	$\hat{Y}$=0.41 + 0.01X**	0.93	20.31
RN/IN, g kg^{-1} N (7)	521.0	502.9	566.0	558.3	578.4	$\hat{Y}$=49.72 + 0.24X*	0.71	9.74

** =P<0.01; * =P<0.05; ns =P>0.05; (1)ingested nitrogen; (2) faecal nitrogen; (3)urine nitrogen; (4)absorbed nitrogen; (5)retained nitrogen (6) retained nitrogen, in grams per unit of metabolic size; (7) ratio of retained nitrogen to ingested nitrogen (RN/IN)

According to Detmann *et al*. (2014), to optimise the rumen environment, there must be synchrony between protein degradation and carbohydrate fermentation in order to obtain increased digestibility and forage intake, and the maximum efficiency for microbial protein synthesis in the rumen. However, when ammonia is produced faster than it is used, there is an increase in nitrogen excretion and the energy cost of urea synthesis, which leads to less protein availability. Therefore, the linear increase in RN found in the present study may be an indication that the addition of babassu cake as a substitute for the roughage improved the efficiency of microbial protein synthesis and, consequently, nitrogen retention by the organism.

Another factor that can influence nitrogen use efficiency and nitrogen retention is the particle size of the feed. According to Dewhurst, Davies and Merry (2000), the greater the surface area exposed to microbial attack (which occurs in diets with a lower roughage content), the greater the increase in RN. The addition of babassu cake may have influenced the particle size of the diets, resulting in the higher values for RN seen in this study.

It is important to note that several agro-industrial by-products include antinutritional factors, bioactive compounds and even toxic compounds (ABDALLA *et al*., 2008), which can hamper intake, digestibility, and performance, and may cause death, facts that were not verified in the present work.

Further study on the kinetics and ruminal dynamics of babassu cake when included in sheep diets could provide additional information on the synchrony between protein degradation, ammonia levels and carbohydrate fermentation, to allow for maximising the production of microbial protein and the nutritional efficiency of the diet.

CONCLUSION

The addition of babassu cake to replace roughage increases the nutritional value of the diet, and can be used as both a protein and energy supplement up to a total of 350 g kg^{-1} DM in the diet as a replacement for Tifton-85 hay.

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