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Ingestive behaviour in heifers fed diets with increasing levels of babassu cake[1]

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ABSTRACT - The aim of this study was to assess the effect of increasing levels of babassu cake on the ingestive behaviour of dairy heifers in confinement. Twenty-four heifers with an average initial weight of 190.8 ± 40.8 kg were fed diets containing babassu cake (0, 100, 200, 300 mg kg^{-1} (dry matter basis) as a substitute for sugar cane, in a completely randomised design with four treatments and six replications. Observations were made every five minutes for 24 hours, assessing rumination, feeding, idle time, sleeping and other activities, in addition to the frequency with which the heifers searched for water, urinated and defecated. The time spent on feeding and rumination decreased by 0.1138% and 0.3106%, respectively, for every 10 g kg^{-1} substitute, while idle time increased by 0.3368% for every 10 g kg^{-1} substitute. The time spent sleeping and on other activities was not affected. Longer feeding times were seen whenever feed was offered, with more rumination activity at night. There was no effect on the specific activities (urination, defecation or drinking); however, urination and drinking were affected by the period, and was more frequent during the day. There was a linear increase in intake, and in feed and rumination efficiency for dry matter and neutral detergent fibre, with a reduction in total chewing time. Substituting babassu cake for sugar cane affects both the ingestive behaviour of dairy heifers and the rumination process as it does not stimulate chewing.

Key words: Feeding. Rumination efficiency. Chewing. *Orbignya* ssp. By-product.

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INTRODUCTION

Various factors can affect ingestive behaviour, either stimulating or inhibiting food intake. Among dietary factors, physical and chemical characteristics such as dry matter content, quantity and source of fibre, fibre and digestibility, particle size, and characteristics of the protein and fat can affect the ingestive behaviour and dry matter intake of ruminants (ALLEN, 2014).

Rumen buffering, which is necessary to maintain suitable conditions in the rumen for the metabolism and growth of rumen microorganisms, is directly related to masticatory activity, i.e. chewing and rumination, which affect the production of saliva and buffering substances (HUMER *et al*., 2018). Therefore, understanding the ingestive behaviour of the animals based on their diet is crucial to adjusting feed management and improving the productive performance of the herd (MISSIO *et al*., 2010).

The amount of feed consumed by the ruminant in any given period depends on the number of meals during that period and the length and feeding rate of each meal. Each of these processes is the result of interaction between the metabolism of the animal and the physical and chemical properties of the diet stimulating the satiety receptors (ALLEN, 2014).

Behavioural patterns reflect the adaptation of animals to various factors, such as diet, and can suggest methods of improving animal productivity by the use of different types of management (GREEN *et al*., 2013). In addition, ruminants can modify one or more components of their ingestive behaviour in order to minimise the effects of unfavourable dietary conditions, thereby meeting their nutritional requirements for maintenance and production (ALLEN, 2014).

Management practices such as the time the diet is offered influence the ingestive behaviour of the animals (CASTRO *et al*., 2009). Therefore, studying the ingestive behaviour of ruminants not only provides data that helps to understand intake patterns, the processes of food digestion and absorption, and the physiological responses (CORREIA *et al*., 2012; MIOTTO *et al*., 2014; OLIVEIRA *et al*., 2014), but can also help in decision-making regarding the feeding and general management of the herd.

In the north and northeast of Brazil, babassu (*Orbignya* ssp.) is one of the principal plants used as a source of raw material in the manufacture of biodiesel, a process that generates many by-products, including babassu cake, that has the potential for use in ruminant feed (CASTRO *et al*., *2009*; OLIVEIRA *et al*., 2014), 2009; OLIVEIRA *et al*., 2014) and can replace an energy ingredient in the concentrate, such as millet (ALENCAR *et al*., 2015), and dietary bulk, such as elephant grass silage (LUZ *et al*., 2019; SANTOS NETA *et al*., 2017). In this respect, knowledge of the ingestive behaviour of animals that receive by-products as part of their diet can help in developing diets and in understanding the problems associated with reduced intake.

The aim of this study was to assess the effect of using babassu cake as a substitute for sugar cane on the ingestive behaviour of dairy heifers in confinement.

MATERIAL AND METHODS

The experiment was carried out at the School of Veterinary Medicine and Zootechnics (EMVZ) of the Federal University of Tocantins (UFT), in Araguaína, located at 07°11’28” S and 48°12’26” W. According to the Köppen classification, the region has a tropical climate (AW) with humid summers and a dry period during the winter.

The ingestive behaviour of 24 mixed-breed dairy heifers (Holstein x Zebu) in confinement, fed diets containing different levels of babassu cake (0, 100, 200, 300 mg kg^{-1} -dry matter basis) as a substitute for sugar cane (*Saccharum officinarum* L.) was evaluated in a completely randomised experimental design with four treatments and six replications. The animals, with an average initial weight of 190.8 kg $\pm$ 40.8 kg and final weight of 299.7 kg $\pm$ 45.5 kg, were identified, wormed and given an injectable vitamin complex (ADE) at the start of the experiment.

The diets were formulated using the RLM 3.2® software to be isoenergetic, with 65% total digestible nutrients (TDN) and isoproteic, with 13% crude protein (CP; Table 1), and a predicted daily dry matter intake of 2.17% of live weight and an average daily gain of 750 g. However, despite being formulated to be isoenergetic and isoproteic, the diets had a different composition to the formulated diets due to variations in the chemical composition tables of the ingredients.

Enough sugar cane was cut to last for up to three days. After cutting, the sugar cane was chopped up and hydrolysed by dissolving 1% livestock lime (CaO - natural matter basis) in water to avoid the presence of bees and allow the cane to be stored for up to 60 hours, eliminating the need for daily cutting. The babassu cake was obtained by mechanically extracting the oil from the babassu kernel.

Each animal occupied a partially covered individual stall (with an area of 12 m^2) with an individual feeding trough, and a drinking trough serving two stalls. Feed was provided twice a day, at 0830 and 1630, as a complete mixture, adjusted to allow for daily leftovers of 10%.

The meteorological data was collected from the main climatological station of the National Institute of Meteorology, at EMVZ, 350 m from the experimental site (Table 2).

The experiment lasted 91 days, including 21 days for adaptation and 70 days for experimental evaluation. Once a week, samples were taken of the leftovers of each animal and of the feed offered (concentrates and bulk).

Table 1 - Percent composition and chemical-bromatological composition of the experimental diets

Ingredients (g kg^{-1} DM[1])	Levels of babassu cake as a substitute for sugar cane (g kg^{-1} DM)			
	0	100	200	300
Sugar cane	600.0	500.0	400.0	300.0
Babassu cake	0.0	100.0	200.0	300.0
Soya bran	183.4	170.6	133.0	88.7
Wheat bran	159.7	27.9	0.0	0.0
Grain maize	35.8	169.0	238.9	291.7
Limestone	6.2	2.5	4.1	5.0
Mineral supplement[2]	15.0	30.0	24.0	14.5
Chemical composition				
Dry matter (g kg^{-1} NM[3])	501.8	562.4	621.7	620.3
Organic matter (g kg^{-1} DM)	935.7	930.3	935.9	948.2
Crude protein (g kg^{-1} DM)	140.4	143.8	147.3	130.4
Neutral detergent fibre (g kg^{-1} DM)	458.1	440.0	437.8	457.4
Acid detergent fibre (g kg^{-1} DM)	233.3	223.6	224.8	236.2
Hemicellulose (g kg^{-1} DM)	224.8	216.4	213.0	221.2
NDIN4 (% total N)	68.4	100.2	110.9	106.8
ADIN5 (% of total N)	4.8	4.7	5.2	4.9
Non-fibre carbohydrates (g kg$_{-1}$ DM)	322.0	326.9	325.2	336.2
Ether extract (g kg^{-1} DM)	15.2	19.6	25.6	24.2
Ca (g kg^{-1} DM)	10.0	10.4	9.2	7.7
P (g kg^{-1} DM)	3.8	4.6	5.1	4.3

[1]Dry matter; [2]FosQuima Super, composition (in 1000g): Na – 150 g, Ca – 118 g, P – 90 g, Mg – 7 g, S – 12 g, N – 10 g, Zn – 3600 mg, Cu – 1730 mg, Co – 200 mg, Mn – 1000 mg, I – 150 mg, Se – 20 mg; [3]Natural matter; [4]Neutral detergent insoluble nitrogen; [5]Acid detergent insoluble nitrogen

Table 2 - Meteorological data on the days of behavioural observation

Day	Time	Temperature ºC	Relative humidity%	DRH[1]%	TMAX[2] ºC	TMIN[3] ºC	INS[4] h day^{-1}	RAIN[5] mm
First observation (04/09/09)	09 h	27.5	67	60.0	36.0	18.8	10.6	0
	15 h	35.2	37					
	21 h	27.2	68					
Second observation (02/10/09)	09 h	27.8	70	71	34.4	19.5	10.3	0
	15 h	33.1	49					
	21 h	25.5	82					
Third observation (23/10/09)	09 h	26.6	79	82	31.7	22.3	6.2	0
	15 h	29.4	71					
	21 h	25.1	89					

[1]Average daily relative humidity; [2]Maximum temperature; [3]Minimum temperature; [4]Direct insolation; [5]Rainfall.

The samples were packed in plastic bags, frozen and then grouped proportionally into 14-day periods to form one composite sample per period. Each of the samples was pre-dried in a ventilated oven at 55 $\pm$ 5 °C for 72 hours, ground in a mill with a 1-mm sieve, and the dry matter content (AOAC, 1995) and neutral detergent fibre content (VAN SOEST; ROBERTSON; LEWIS, 1991) determined with the addition of thermo-resistant amylase using the ANKOM fibre analyser. Intake was expressed as a percentage of live weight (% BW).

The behavioural observations were carried out on days 13, 40 and 61 of the trial, over twenty-four consecutive hours divided into four six-hour periods starting at 0800. Feeding, rumination, idle time, sleeping and other activities were assessed every five minutes. Specific activities (urination, defecation or drinking) were also measured and recorded whenever they occurred. Artificial lighting was used at night, to which the animals had previously been adapted for six days.

Idle time was considered as the animals not performing any activity, whether standing or lying down, and with their eyes open. Other activities were considered as the animals licking themselves, playing, observing or moving around the stall, i.e. when they were awake, but neither idle, eating or ruminating. Sleeping was considered as the animals at rest, with their eyes closed.

The assessments were made by trained observers, visually and individually for each animal. Each observer was responsible for a group of four animals, taking turns in three-hour shifts.

The data on feeding, rumination, idle time, sleeping and other activities as a function of the levels of babassu cake as a substitute for sugar cane were analysed in hours per day and as a percentage of the activity over 24 hours, and also as a percentage of time within each period of the day, or the share of each activity during each six-hour period. The specific activities were tabulated in terms of frequency (number of times each animal performed a given activity during each six-hour period).

On the second day after the behavioural observations (days 15, 42 and 63 of the experimental period), the activities related to rumination were assessed, counting the number of re-chews and re-chewing time per cud bolus. The animals were individually observed for three periods daily, from 0600 to 0800, from 1300 to 1500, and from 2000 to 2200; three cud boluses were observed per animal during each observation period. The number of re-chews was counted from the moment each cud reached the mouth until it was swallowed; at the same time, the time spent ruminating each bolus was recorded using a digital timer.

The number of re-chews per day was estimated as per Bürger *et al*. (2000), using the formulae:

$$NBR = \frac{TRU}{TBR} \quad (1)$$

$$NMD = BRD \times NMB \quad (2)$$

where: NCB = number of cud boluses per day; RUT = rumination time in minutes per day; RCT = re-chewing time per cud bolus in minutes per bolus; NRC = number of re-chews per day; NRB = number of re-chews per bolus.

The variables that indicate feeding efficiency were determined as per to Polli *et al*. (1996):

$$EALMS = \frac{CMS}{TAL} \quad (3)$$

$$EALFDN = \frac{CFDN}{TAL} \quad (4)$$

$$ERMS = \frac{CMS}{TRU} \quad (5)$$

$$ERFDN = \frac{CFDN}{TRU} \quad (6)$$

$$TMT = TAL + TRU \quad (7)$$

where: FEDMI = feed efficiency for dry matter intake (DM; kg h^{-1}); FENDF = feed efficiency for neutral detergent fibre intake (NDF; kg h^{-1}); DMI = daily DM intake (kg day^{-1}); NDFI = daily NDF intake (kg day^{-1}); TFE = time spent feeding (h); DMRE = DM rumination efficiency (kg h^{-1}); NDFRE = NDF rumination efficiency (kg h^{-1}); RUT = rumination time (h day^{-1}; TCT = total chewing time (h day^{-1}).

Intermittent and specific activities, and the variables NCB, RCT, NRC, NRB, FEDMI, FENDF, DMRE, NDFRE and TCT were assessed using regression analysis at 5% significance, considering the levels of babassu cake replacing sugar cane as independent variables. For the specific activities, when the periods of the day were considered independent variables, the data was analysed using Tukey's test at 5% significance. The interaction between treatment and time of day was only analysed when significant at 5%. The SISVAR® statistical software was used.

RESULTS AND DISCUSSION

The time spent daily on feeding, as a percentage and in hours, showed a decreasing linear response, with a reduction of 0.01138% and 0.00273 h for each g kg^{-1} of sugar cane that was substituted by babassu cake (Table 3). This reduction in feeding time was possibly due to the lower bulk to concentrate ratio and to the higher dry matter content of the diets with added babassu cake (Table 1), since Oliveira *et al.* (2007) explained that the longer feeding time of Holstein cows fed a diet consisting of 60% corn silage and 40% concentrate (DM basis) was due to the higher moisture content of the diet. According to these authors, the animals increase their feeding time to compensate for the lower DM content per mouthful.

Despite the reduction in the time spent on feeding, dry matter intake as a function of live weight showed increasing linear behaviour ($P < 0.05$), with averages of 2.58%, 2.88%, 3.11% and 3.04%, respectively, for the diets with 0, 100, 200 and 300 g kg^{-1} of added residue (Table 7), probably because the animals fed no babassu cake, or lower levels of this feed, had their consumption regulated by the physical filling of the gastrointestinal tract due to spending more time eating to meet their nutritional needs (ALLEN, 2014).

The average time spent ruminating per day, as a percentage and in hours, showed decreasing linear behaviour ($P < 0.05$), with a reduction of 0.03106% in ruminating time or 0.00744 h for each g kg^{-1} of sugar cane substituted by babassu cake. The rumination time varied from 6.98 hours for the animals fed the diet with the highest level of added babassu cake to 9.21 hours for the diet with no babassu cake, representing 29.07% and 38.39% of the day, respectively.

These results corroborate those of Bürger *et al.* (2000) and Missio *et al.* (2010), who also observed a decreasing linear effect on the time spent feeding and ruminating when they increased the amount of added concentrate in the diet of Holstein calves (30%, 45%, 60%, 75% and 90%) and bulls in confinement (22%, 40%, 59% and 79%). However, their results differ from those of Gonçalves *et al*. (2019), who found an increasing linear effect for the addition of dehydrated brewery residue in the concentrate portion of the diet, and pointed out that this result could be a function of the increase in NDF content, since the time spent ruminating increases linearly with increases in the level of this nutrient.

According to Santos Neta *et al.* (2017), the effectiveness of fibre in stimulating rumination is affected by the NDF content and particle size. These characteristics are associated with the ability of the feed to stimulate chewing and the release of substances in the saliva that act to maintain the pH and rumen health (HUMER *et al.*, 2018). In the present study, although the NDF content remained constant (Table 1), the bulk to concentrate ratio decreased as more babassu cake was added, which probably reduced the particle size and, consequently, the time spent ruminating.

However, the results differed from those of Alencar *et al.* (2015), who found no effect on feeding time, but saw an increasing linear effect on rumination time that ranged from 23.99% to 29.72% day^{-1} in Holstein-Zebu crossbred steers fed diets containing increasing levels of babassu mesocarp bran (0, 120, 240, 360, 480 g kg^{-1}) as a substitute for millet in a diet with 20% bulk. This was probably due to the lower levels of metabolisable energy in the diets with added babassu mesocarp bran, leading the authors to conclude that moderate levels of added babssu do not compromise the feeding time of the animals, which adjust between rumination and idle time; albeit, the addition of more than 360 g kg^{-1} impairs the productive performance of the animals.

Araújo *et al.* (2019) found no effect from adding babassu cake as a substitute for maize (0%, 25% and 50%) in cow diets on the time spent ruminating or re-chewing; they did, however, find an increasing linear effect on intake time in minutes per day. The authors

Table 3 - Time spent daily by heifers on activities based on the levels of babassu cake as a substitute for hydrolysed sugar cane

Variable	Level of substitution (g kg^{-1})				SEM[1]	P-value
	0	100	200	300		
Feeding[2] (%)	18.81	16.84	16.46	15.14	1.0149	0.0209
Feeding[3] (h)	4.52	4.04	3.95	3.64	0.2438	0.0210
Rumination[4] (%)	38.39	34.34	31.23	29.07	1.2181	<0.0001
Rumination[5] (h)	9.21	8.24	7.50	6.98	0.2925	<0.0001
Idle time[6] (%)	27.35	32.53	36.38	37.30	1.6633	0.0002
Idle time[7] (h)	6.57	7.81	8.73	8.95	0.3992	0.0002
Other activities (%)	9.22	9.12	10.80	11.73	0.9994	0.0527
Other activities (h)	2.21	2.19	2.59	2.82	0.2395	0.0521
Sleeping (%)	6.23	7.18	5.14	6.76	1.0256	0.9234
Sleeping (h)	1.50	1.72	1.23	1.62	0.2460	0.9166

[1]Standard error of the mean; [2]$\hat{Y} = 18.5185 – 0.01138X$ ($R^2 = 0.94$); [3]$\hat{Y} = 4.4453 – 0.00273X$ ($R^2 = 0.94$); [4]$\hat{Y} = 37.9158 – 0.03106X$ ($R^2 = 0.98$); [5]$\hat{Y} = 9.0988 – 0.00744X$ ($R^2 = 0.98$); [6]$\hat{Y} = 28.3360 + 0.03368X$ ($R^2 = 0.92$); [7]$\hat{Y} = 6.8012 + 0.00809X$ ($R^2 = 0.92$)

believe that the longer ingestion time could be related to some intrinsic characteristic of babassu cake that might cause low acceptance of the experimental diets. However, Santos Neta *et al*. (2017) and Luz *et al*. (2019) found no problems related to the acceptability of babassu cake when included at varying levels as a substitute for elephant grass silage in sheep diets, recommending a substitution of up to 50% of the DM in the diet.

On the other hand, idle time had an increasing linear effect (P = 0.0002), with an increase of 0.03368% and 0.00809 h for each g kg^{-1} of sugar cane substituted by babassu cake, ranging from 27.35% to 37.30%; whereas the feed had no effect on the time spent on other activities or sleeping, which ranged from 9.12% to 11.73% and from 5.14% to 7.18%, respectively. This result differs from that of Sá *et al.* (2015), who included babassu cake as a substitute for elephant grass silage in the diet of mixed-breed sheep and found a decreasing linear result for idle time. In ruminants, the time spent on idleness, although short, can indicate well-being (SPIGARELLI *et al*., 2020), in addition to rumination stimuli, which may also allow physiological rest and physical recovery, normally provided by deep sleep in other species.

Studying the overall averages of the variables analysed during each of the four six-hour periods, the longest times spent feeding were seen during the first two periods, which includes the times the diets were offered (0830 and 1630; Table 4). The same was found by Castro *et al*. (2009) when assessing the ingestive behaviour of heifers fed different by-products (maize germ, cornmeal and babassu cake), and by Green *et al.* (2013), studying the ingestive behaviour of growing heifers.

According to Fischer *et al.* (2000), ruminants in confinement fed twice a day have two main meals that occur after the diet is offered (lasting 1 to 3 hours), as well as a variable number of small meals in between, as was seen in the present study, with the animals spending more time feeding during the morning and afternoon.

The animals spent more time ruminating at night. This can be explained by the increase in heat production due to the digestive processes, which causes the animals to carry out this activity at times when the ambient temperature is lower in order to maintain their body temperature (Table 2).

During the observation periods, the animals spent the most idle time after meals and during the hottest times of the day, which included from 0800 to 1400. Castro *et al.* (2009), working with heifers, found similar behaviour and explained it by the greater temperature and sunshine at these times. The ingestive behaviour of ruminants has a heterogeneous nychthemeral distribution and is affected by such factors as management, nutrition and environmental conditions, especially temperature (CAMPANA *et al*., 2015), which would explain the results for idle time.

The time spent sleeping was greater at night, with higher average values during the early hours of the morning (0200 to 0800), which corresponded to 38.93% of this activity over 24 hours. On the other hand, the time spent on other activities was greater from 1400 to 2000. This period began between meals when the animals spent less time feeding or ruminating. Miotto *et al.* (2014), who assessed the ingestive behaviour of bulls given increasing levels of whole maize germ in the concentrate portion of their diet, also found similar behaviour, with more time spent on other activities between 1700 and 2000. According to these authors, food satiety and milder temperatures can stimulate the animals to carry out other activities, such as observing, playing and walking.

It can be seen that from 1400 to 2000 there was an interaction between treatment and time period for feeding and other activities, with a decreasing linear response (P = 0.0022) for time spent feeding and an increasing linear response (P = 0.0441) when carrying out other activities (Table 5). The increase in time spent on other activities by the animals fed babassu cake was due to the reduction in time spent on feeding and rumination during this period.

Table 4 - Percentage of the day spent on activities in heifers receiving added levels of babassu cake as a substitute for hydrolysed sugar cane

Variable (% $period^{-1}$)	Time of day (h)[2]				SEM[1]	P-value
	0800-1400	1400-2000	2000-0200	0200-0800		
Feeding	26.11 a	25.51 a	9.95 b	5.67 c	0.8442	<0.0001
Rumination	23.29 b	25.54 b	40.48 a	43.71 a	1.2338	<0.0001
Idle time	36.44 a	28.50 b	34.72 a	33.89 ab	1.4992	<0.0001
Sleeping	3.25 b	4.03 b	8.17 a	9.85 a	0.6813	<0.0001
Other activities	10.91 b	16.42 a	6.67 c	6.88 c	0.8716	<0.0001

[1]Standard error of the mean; [2]Mean values on the same line followed by different letters differ (P < 0.05) by Tukey’s test

Table 5 - Continuous activities for each period of the day in heifers receiving added levels of babassu cake as a substitute for hydrolysed sugar cane

Period	Level of substitution (g kg^{-1})				SEM[1]	P-value
	0	100	200	300		
Feeding (min)[2]						
0800-1400	105.17 a	90.33 a	91.17 a	89.17 a	5.9054	0.0783
1400-2000[3]	101.17 a	100.50 a	88.83 a	77.17 a	5.9054	0.0022
2000-0200	40.50 b	33.17 b	36.33 b	33.17 b	5.9054	0.4780
0200-0800	24.00 b	18.17 b	20.83 b	18.50 b	5.9054	0.6020
Ruminaton (min)[2]						
0800-1400[4]	107.50 b	87.00 b	73.17 b	68.00 b	7.5356	0.0002
1400-2000[5]	104.83 b	98.17 b	90.00 b	75.33 b	7.5356	0.0053
2000-0200[6]	163.33 a	153.00 a	134.50 a	132.00 a	7.5356	0.0013
0200-0800[7]	177.17 a	156.50 a	152.17 a	143.67 a	7.5356	0.0026
Idle time (min)[2]						
0800-1400[8]	105.83 a	125.83 a	145.50 a	147.50 a	9.5737	0.0012
1400-2000[9]	79.33 a	100.33 a	107.83 b	122.67 a	9.5737	0.0020
2000-0200	108.33 a	125.83 a	134.50 ab	131.67 a	9.5737	0.0703
0200-0800[10]	100.67 a	116.50 a	135.67 ab	135.00 a	9.5737	0.0056
Other activities (min)[2]						
0800-1400	31.33 b	41.33 a	40.00 b	44.83 b	5.9132	0.1428
1400-2000[11]	58.50 a	44.50 a	62.67 a	70.50 a	5.9132	0.0441
2000-0200	17.83 b	16.17 b	36.33 bc	25.67 b	5.9132	0.1029
0200-0800	25.00 b	29.33 ab	16.33 c	28.33 b	5.9132	0.9100
Sleeping (min)[2]						
0800-1400	10.17 c	15.67 b	10.00 b	11.17 b	4.9700	0.9050
1400-2000	16.00 bc	16.83 b	11.00 b	14.67 b	4.9700	0.6600
2000-0200	30.00 ab	32.00 a	18.50 b	37.33 a	4.9700	0.7037
0200-0800	33.33 a	39.00 a	34.67 a	34.50 a	4.9700	0.9702

[1]Standard error of the mean; [2]Mean values on the same line followed by different letters differ (P<0.05) by Tukey's test; [3]$\hat{Y} = 104.4667 - 0.08367X$ ($R^2 = 0.91$); [4]$\hat{Y} = 103.7667 - 0.13233X$ ($R^2 = 0.94$); [5]$\hat{Y} = 106.5833 - 0.09667X$ ($R^2 = 0.96$); [6]$\hat{Y} = 162.5833 - 0.11250X$ ($R^2 = 0.93$); [7]$\hat{Y} = 173.1000 - 0.10483X$ ($R^2 = 0.90$); [8]$\hat{Y} = 109.4667 + 0.14467X$ ($R^2 = 0.92$); [9]$\hat{Y} = 81.9167 + 0.13750X$ ($R^2 = 0.97$); [10]$\hat{Y} = 103.6333 + 0.12217X$ ($R^2 = 0.89$); [11]$\hat{Y} = 50.9167 + 0.05417X$ ($R^2 = 0.41$)

Analysing the diet x period interaction showed that for each period the time spent ruminating decreased when babassu cake substituted the sugar cane, with a reduction ranging from 0.09667 to 0.13233 minutes per period for each g kg^{-1} of babassu cake. According to Izumi, Miwa and Ishizuka (2014), by-products that contain high levels of non-forage fibre can replace both the forage and concentrate in ruminant diets. However, due to its smaller particle size, this type of fibre is not physically effective, which implies a faster rate of passage through the rumen and lower fibre digestibility, consequently stimulating less rumination (MERTENS, 1997), a fact that was seen in the present study.

Idle time showed the opposite response to that seen for time spent in rumination, with increasing linear behaviour ($P < 0.05$) for the addition of babassu cake. This can be explained by the reduction in time spent ruminating, followed by the animal becoming idle.

When assessed over a 24-hour period, the specific activities (urination, defecation and drinking) were not affected by the diets ($P > 0.05$; Table 6). However, urination and drinking varied within each period ($P < 0.0001$), whereas the periods had no effect on defecation ($P = 0.9966$).

It was found that the animals went to the water trough more often during the day (0800 to 2000) when the ambient temperature was higher; urination was consequently also higher during these periods. According to Spigarelli *et al.* (2020), in ruminant production systems, special attention should be paid to providing water, which directly affects the welfare of the animals. The increased need for water to cool the body due to stress or caloric gain heightens the need to drink and affects water metabolism.

The number of re-chews per bolus (NRB) and the number of re-chews per day (NRC) showed decreasing linear behaviour ($P < 0.05$; Table 7). This can be explained by the reduction in the bulk to concentrate ratio (B:C) of the feed, and the fact that the cake is a source of non-forage fibre, which is less physically effective and therefore promotes less re-chewing activity (IZUMI; MIWA; ISHIZUKA, 2014; LI, *et al*., 2014). As such, the difference in the physical characteristics of the diets influenced rumination behaviour, with the babassu cake not contributing to increased rumination.

Table 6 - Count of specific activities, over 24 hours and by period of the day, in heifers receiving added levels of babassu cake as a substitute for hydrolysed sugar cane

Variable	Level of substitution (g kg^{-1})				SEM[1]	P-value
	0	100	200	300		
Urination	7.28	9.89	7.56	9.36	0.8799	0.3321
Defecation	7.05	9.39	8.94	7.78	0.9535	0.6901
Drinking	7.94	8.11	9.00	11.67	1.5640	0.1003
	Time of day (h)[2]					
	8 - 14	14 - 20	20 - 02	02 - 08		
Urination	2.50 a	2.67 a	1.71 b	1.75 b	0.9370	< 0.0001
Defecation	2.04	2.04	2.13	2.04	0.8200	0.9966
Drinking	3.58 a	3.63 a	1.17 b	0.75 b	1.8113	< 0.0001

[1]Standard error of the mean; [2]Mean values on the same line followed by different letters differ ($P < 0.05$) by the Friedman test ($P < 0.05$) with the Dunn post-hoc test ($P < 0.05$)

Table 7 - Variables of feeding and rumination in heifers as a function of the amount of babassu cake added as a substitute for hydrolysed sugar cane

Variable	Level of substitution (g kg^{-1})				SEM[1]	P-value
	0	100	200	300		
DMI[2]	2.58	2.88	3.11	3.04	0.1301	0.0112
NDFI[3]	1.11	1.17	1.33	1.23	0.0538	0.0419
NMB[4]	65.65	64.35	54.31	52.40	3.6817	0.0067
NRC[5]	39.372.52	33.213.26	28.811.87	26.962.56	1412.07	<0.0001
RCT[6]	55.56	57.87	50.75	48.93	3.6293	0.1116
NCB[7]	602.30	520.74	534.23	538.96	34.8819	0.2712
TCT[8]	13.73	12.28	11.44	10.61	0.3954	<0.0001
FEDMI[9]	1.38	1.82	1.89	2.22	0.2097	0.0128
FENDF[10]	0.59	0.74	0.81	0.89	0.0812	0.0152
DMRE[11]	0.67	0.87	0.98	1.11	0.0718	0.0003
NDFRE[12]	0.29	0.35	0.42	0.45	0.0270	0.0002

[1]Standard error of the mean; [2]Dry matter intake as a percentage of live weight (BW), $\hat{Y} = 2.6567 + 0.00162X$ ($R^2 = 0.79$); [3]Neutral detergent fibre intake as a percentage of BW, $\hat{Y} = 1.1323 + 0.00052X$ ($R^2 = 0.51$); [4]Number of re-chews per cud bolus, $\hat{Y} = 66.6493 - 0.04980X$ ($R^2 = 0.90$); [5]Number of re-chews per day, $\hat{Y} = 38334.7413 - 41.63126X$ ($R^2 = 0.95$); [6]Time spent per cud bolus (s); [7]Number of cud boluses per day; [8]Total chewing time (h day^{-1}), $\hat{Y} = 13.5435 - 0.01018X$ ($R^2 = 0.98$); [9]DM feed efficiency (kg DM h^{-1}), $\hat{Y} = 1.4415 + 0.00256X$ ($R^2 = 0.94$); [10]Feed efficiency NDF (kg NDF h^{-1}), $\hat{Y} = 0.6148 + 0.00096X$ ($R^2 = 0.97$); [11]Rumination efficiency DM (kg DM h^{-1}), $\hat{Y} = 0.6932 + 0.00142X$ ($R^2 = 0.98$); [12]Rumination efficiency NDF (kg NDF h^{-1}), $\hat{Y} = 0.2947 + 0.00055X$ ($R^2 = 0.97$)

Rumination has the aim of reducing the size of the food particles, facilitating their degradation, digestion and passage; the amount of chewing carried out on the cud bolus is influenced by the size of the particles as well as their resistance to size reduction. To be used in feed, babassu cake undergoes a milling process, so that the more it replaces the sugar cane, in addition to reducing the B:C ratio, diets with greater levels of cake become denser, with smaller particles and, consequently, less physically effective fibre.

The number of re-chews per day (NRC) of the diet with no babassu cake was 18.54%, 36.65% and 46.03% higher than in diets with 100, 200 and 300 g kg^{-1} of babassu cake as a substitute for sugar cane, respectively. The number of re-chews per bolus (NRB) varied from 52.40 to 65.65 between diets, with a reduction of 0.04980 re-chews per g kg^{-1} of babassu cake replacing the sugar cane.

For the addition of 200 g kg^{-1} babassu cake, 54.31 re-chews were observed per cud bolus, a similar value to that obtained by Oliveira *et al.* (2014), evaluating the ingestive behaviour and physiological responses of male cattle fed diets containing peanut cake as a substitute for soybean meal (56.24 re-chews per cake), and Missio *et al*. (2010), working with 59% concentrate in the diet of bulls (53.2 re-chews per cud bolus). Missio *et al*. (2010) also reported that reducing the amount of bulk in the diet reduced the number of cud boluses per day (NCB), and that this was undoubtedly due to a reduction in the percentage of long fibre.

The rumination time of each bolus (RCT) and NCB were not influenced by the diets, with an average of 53.28 seconds $bolus^{-1}$ and 549.06 boluses day^{-1}, respectively: lower than the 56.20 to 59.40 seconds $bolus^{-1}$ and 579 to 609 boluses day^{-1} obtained by Oliveira *et al.* (2014) for diets with groundnut cake added to the concentrate. The lower values seen in the present study were probably due to the lower bulk to concentrate ratio and the consequent lower need for rumination.

It can be seen that despite the decreasing linear effect on NRB and NRC, there was no effect on RCT or NCB, which shows that the less babassu cake used to replace the bulk, the more efficient the re-chewing, probably to ensure sufficient intake to meet the daily requirements of the animals.

As expected, total chewing time (TCT), which is the sum of the daily time spent feeding and ruminating, also showed a decreasing linear response, with a reduction of 0.01018 h day^{-1} for each g kg^{-1} of sugar cane replaced by babassu cake ($P < 0.0000$), confirming that the animals reduced their daily chewing time due to greater efficiency in reducing the size of the particles, which can occur as a result of various factors, including an increase in the rate of jaw movements, and a reduction in the interval between cud boluses.

Increasing linear behaviour ($P < 0.05$) was seen for dry matter feed efficiency (FEDMI) and neutral detergent fibre feed efficiency (FENDF), as well as for rumination efficiency (DMRE and NDFRE). The increase in feeding and rumination efficiency is primarily influenced by intake, which in turn can affect the time spent feeding and ruminating, and idle time (CARVALHO *et al*., 2004), and are also associated with the higher specific weight of the concentrate fraction and the neutral detergent fibre content, as well as the properties of the fibre in the babassu cake, allowing the animal to ingest more food in less time (MISSIO *et al*., 2010), and reducing the number of re-chews per cud bolus and the total re-chewing time (Table 7).

These results differ from those of Correia *et al*. (2012), who found no effect on DM or NDF intake, or rumination efficiency when evaluating the addition of by-products of biodiesel production (palm kernal, peanut and sunflower cake) as a substitute for soya meal in the diet of steers, which was probably due to using a higher bulk to concentrate ratio (65:1) than in the present study, and the bulk (Tifton-85 hay) affording a high fibre intake, regulating consumption through the physical effect of the fibre.

The results for DMRE and NDFRE lead to the conclusion that babassu cake, even with a high fibre content similar to that found in bulky foods, did not continue to stimulate rumination, which is probably due to the low physical effectiveness of the fibre when compared to that of sugar cane.

CONCLUSIONS

1. The addition of babassu cake to diets with high levels of concentrate does not stimulate the animals to chew, affecting the rumination process;
2. Studies to evaluate the physical effectiveness of babassu cake fibre are needed to better understand its effect on the rumination process.

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