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Feeding behavior of sheep fed sugarcane silage enriched with detoxified castor bean meal

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ABSTRACT. The aim of this study was to evaluate the feeding behavior of sheep fed sugarcane silage enriched with increasing levels of detoxified castor bean meal. Twenty-four non-castrated male Santa Inês sheep with an average body weight of 25.34 kg and four months of age, were distributed in four treatments - 0, 7, 14 and 21% of the natural matter of detoxified castor bean meal in sugarcane silage. There was a linear increase ($p < 0.05$) in time spent eating and feeding and rumination efficiency (g MS and NDF/h) with the inclusion of castor bean meal in silage. However, there was a linear decreasing response for time spent resting ($p < 0.05$). Time spent ruminating, number of boluses per day and numbers of chews per day per bolus were not affected ($p > 0.05$) by the inclusion of castor bean meal. The addition of detoxified castor bean meal to sugarcane silage reduces time spent eating and increases feed and rumination efficiency in sheep.

Keywords: rumination; intake; ethology; feeding efficiency; rumination efficiency; chewing.

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Introduction

Sugarcane presents high yield per area (80 ton ha^{-1}) and high soluble carbohydrate content (Schmidt et al., 2011). These characteristics are desirable for the ensiling process. However, the conservation of sugarcane by silage presents a serious limitation related to dry matter losses due to the conversion of soluble sugars into ethanol (Cavali et al., 2010; Martins et al., 2015). Daniel et al. (2013) found that sugarcane silages can contain up to 22% volatile compounds, with ethanol representing most of it. From de ensiling process, there is roughage rich in neutral detergent insoluble fiber (77%) and with a low crude protein content (4%) (Gomes et al., 2015).

Due to the low nutritive value of sugarcane silage and ensiling problems (Baliero Neto et al., 2009), the use of additives to reduce dry matter losses and to improve the chemical-bromatological composition of the silage is recommended (Amaral et al., 2009). Absorbent products such as meals with high content of dry matter and crude protein seem to be the most indicated additives (Santos, Magalhães, Conceição, Carvalho, & Ferreira, 2018). Castor bean meal is a by-product originated from the extraction of castor bean oil, which is toxic *in natura*, but when treated with calcium hydroxide loses its toxicity (Oliveira et al., 2010) and can be used in animal nutrition. The detoxified castor bean meal presents 91.5 ± 0.3% dry matter, 11.1 ± 4.2% mineral matter, 35.2 ± 5.0% crude protein, 34.9 ± 7.0% neutral detergent insoluble fiber and 34.6 ± 7.9% acid detergent insoluble fiber (Oliveira et al., 2015; Ribeiro et al., 2014).

According to Macedo et al. (2007), it is fundamental to study its constituents to understand how animals respond to interactions between ruminants and diets aiming at increasing DM intake. Thus, the evaluation of feeding behavior may create mechanisms that will be used as an aid tool to understand how these interactions influence intake (Silva et al., 2006). Therefore, the aim of this study was to evaluate if the feeding behavior of sheep is affected by the inclusion of increasing levels of detoxified castor bean meal to sugarcane silage.

Material and methods

The experiment was carried out in the municipality of Itapetinga, BA, located at 15°14'56"S and 40°14'52" W. According to Köppen and Geiger (1928), the municipality's climate is classified Aw with average temperature of 23.6°C and rainfall of 857 mm.

Twenty-four non-castrated male Santa Inês sheep used, with a body weight of 25.34 kg and an average of four months of age. The animals were kept in individual pens of 1.5 m^2 equipped with feeder and drinking fountain. The pens were allocated in an open shed, covered with asbestos roof tiles, with a ceiling height of 3.5m and were kept with artificial lighting.

The treatments consisted of four levels of castor bean meal inclusion (0, 7, 14 and 21% NM) during the silage process. Sugarcane without straw was used to produce silage. Sugarcane was chopped into particles of approximately 2 cm in a silage machine coupled to a tractor. The castor bean meal was purchased from agribusiness in the metropolitan region of Salvador-BA, which was previously detoxified using lime solution $Ca(OH)_2$. Each kg was diluted in 10 liters of water and applied in the amount of 60 grams of lime per kg of meal at natural matter basis, as recommended by Oliveira et al. (2015). After mixing the meal with the lime solution, the material stayed still for twelve hours (overnight). After that, it was dried, and the drying time varied from 48 to 72 hours, depending on the climatic conditions. Castor meal was added to freshly chopped sugarcane at the levels of 0, 7, 14 and 21% on a natural matter basis (Table 1). Metal drums were used as silos with a volume of 200 L, in which 150 kg of the fresh mixture were placed at a density of 750 kg m^{-3}. After filling them, the silos have been sealed with plastic canvas for 60 days.

The diets were formulated to provide 200 g day^{-1} (National Research Council [NRC], 2007) based on 60% sugarcane silage and 40% concentrate composed of corn, soybean meal and mineral mixture (Table 2). The diets were provided *at libitum* in two daily meals for 87 days – 15 days of adaptation and 72 days of experiment. Throughout the experiment, food intake was adjusted so that the animals had 10% more of the natural matter received in the trough.

To estimate the voluntary intake of roughage was used indigestible internal marker NDF (NDFi) obtained after ruminal incubation for 240 hours (Casali et al., 2008), 0.5 g of food samples, leftovers and feces using bags made with non-woven fabric (TNT) (100 g m^{-2}), 5 x 5 cm. The remaining material from the incubation was subjected to neutral detergent extraction for iNDF determination. Dry matter intake (DMI) of roughage was calculated as follows: $\text{DMI (kg day}^{-1}) = \{(\text{FE} \times \text{ICF}) \div \text{ICR}\}$, where: EF = fecal excretion (kg day^{-1}), obtained using LIPE®, ICF = indicator concentration in feces (kg kg^{-1}) and ICR = indicator concentration in roughage (kg kg^{-1}).

The DM intake of concentrate was estimated using titanium dioxide indicator, which was supplied in the amount of 5 g per animal, mixed to the concentrate, for 11 days from the 27th day of the experimental period. The feces were collected from the 34th to the 38th day, pre-dried, ground and composted, as reported above. The determination of titanium concentration was done through acid digestion with sulfuric acid at 400° C, followed by the addition of 30% hydrogen peroxide, transfer to volumetric flask, filling the volume to 100 mL and filtration to obtain the solution. The reading was performed by an atomic absorption spectrophotometer.

Dry matter (DM), ash, crude protein (CP), ethereal extract (EE), neutral detergent fiber (NDF) and acid detergent fiber (ADF) in feed, leftovers and feces samples were analyzed according to INCT-CA (2012). The organic matter content (OM) was estimated by reducing the ash content of the DM value. Total carbohydrates (TC) were estimated according to Sniffen, O'Connor, Van Soest, Fox, and Russell (1992), as: $\text{TC} = 100 - (\%\text{CP} + \%\text{EE} + \%\text{ASH})$. The contents of non-fibrous carbohydrate corrected for ash and protein (NFCap) were calculated as proposed by Hall (2003), where: $\text{NFCap} = (100 - \%\text{NDFap} - \%\text{CP} - \%\text{EE} - \%\text{ASH})$. Estimated total digestible nutrient contents (TDNest) of food and total diets were calculated according to the equations described by NRC (2001).

Observations regarding animal behavior were visually and simultaneously performed by three evaluators for two periods of 24 hours, at 5-minute intervals. The observed and recorded behavioral variables were: time spent eating, ruminating and resting. Time spent eating and ruminating was also calculated as a function of DM and NDF intake (min kg^{-1} DM or NDF).

The counts of the number of merciful chews and the determination of the time spent ruminating of each bolus for each animal were counted using a digital chronometer. To obtain the means of chewing and time, observations of three ruminal boluses were made in three different periods of the day (09-12, 15-18 and 19-21 hours). To obtain the number of daily boluses, the total rumination time was divided by the average time spent ruminating of each bolus, previously described by Burguer et al. (2000).

Table 1. Percent composition of the experimental diets (dry matter basis %DM).

Ingredients (% DM)	Level of castor bean meal (% NM)			
	0	7	14	21
Sugarcane silage	60.0	55.8	51.6	47.4
Castor bean meal	0.0	4.2	8.4	12.6
Soybean meal	30.4	20.72	13.4	10.32
Ground corn	8.4	18.08	25.4	28.48
Mineral mix	1.2	1.2	1.2	1.2
Total	100	100	100	100

NM: natural matter.

Table 2. Chemical composition of castor bean meal (CBM), silages and experimental diets (dry matter basis %DM).

Composition (%)	CBM	Level of castor bean meal (%NM[3])			
		0	7	14	21
Feed constituents (%)					
Dry matter	91,8	20,9	28,7	32,9	37,0
Crude protein	38,8	2,2	10,4	15,2	18,5
Neutral insoluble detergent protein (%CP)	10,2	0,6	2,8	4,0	5,0
Acid insoluble detergente protein (%CP)	4,0	0,8	2,3	2,6	3,1
Ethereal extract [1]	1,8	2,8	2,8	2,7	2,4
Ash[1]	14,1	4,4	6,7	8,4	9,3
Total Carbohydrate[1]	43,9	90,6	80,1	73,7	69,8
Neutral detergente fiber[1]	39,5	62,5	52,9	49,6	51,0
NDFap[1]	30,1	59,7	47,7	40,1	40,7
Acid detergente fiber	29,3	46,7	40,2	38,7	39,8
Lignin [1]	7,0	5,9	6,43	7,06	7,79
Non-fibrous carbohydrates[1]	20,2	28,6	32,1	30,9	28,9
Total digestible nutrients[2]	60,7	63,7	62,4	60,6	58,7
Diet Constituents (%)					
Dry matter	-	92,4	91,9	91,9	91,7
Crude protein	-	17,9	18,8	18,8	18,9
Neutral insoluble detergent protein (%CP)	-	1,7	2,9	3,8	4,2
Acid insoluble detergente protein (%CP)	-	1,5	2,4	2,5	2,9
Ethereal extract [1]	-	2,5	2,6	2,6	2,4
Ash[1]	-	5,7	6,6	7,4	8,0
Total Carbohydrate[1]	-	81,6	78,9	77,9	77,5
Neutral detergente fiber[1]	-	43,1	37,6	35,6	36,2
NDFap[1]	-	41,4	34,5	29,9	30,1
Acid detergente fiber	-	30,3	29,2	24,3	25,8
Lignin [1]	-	3,7	6,8	7,1	8,6
Non-fibrous carbohydrates[1]	-	39,1	44,3	46,3	47,2
Total digestible nutrients[2]	-	1,7	2,9	3,8	4,2
Dry matter	-	69,7	69,4	68,6	67,4

[1]% DM; [2]estimated according to National Research Council (NRC, 2001); [3]NM: natural matter.

The discretization of the time series was done directly in the data collection worksheets, with the counting of discrete feeding, rumination and resting periods. The average duration of each of the discrete periods was obtained by dividing the daily times of each activity by the number of discrete periods (Silva et al., 2006).

The variables g of DM and NDF were obtained by dividing the mean individual intake of each fraction by the number of feeding periods per day (in 24 hours). The feed and rumination efficiency, expressed in g DM $hour^{-1}$ and g NDF $hour^{-1}$ were obtained by dividing the average daily intake of DM and NDF by the total time spent eating and/or rumination in 24 hours, respectively. The variables g of DM and NDF $bolus^{-1}$ were obtained by dividing the individual average intake of each fraction by the number of ruminated boluses per day (within 24 hours).

Data were evaluated through analysis of variance and regression, using the System of Statistical and Genetic Analysis (SAEG, 2007). The statistical models were chosen according to the coefficients of determination (r^2) and the significance of the regression coefficients, using the F test at 5% probability.

Results and discussion

The inclusion of detoxified castor bean meal (DCBM) in silage promoted a negative linear response for time spent eating ($p < 0.05$) and positive linear response for time spent resting ($p < 0.05$) (Table 3). Probably the reduction of NDF in the diet (41.4% to 30.1% NDF at the level of 0 and 21% DCBM) and replacement of natural sugarcane matter by DCBM (20.9 to 37% DM of silage, at the level of 0% and 21% DCBM) resulted in a denser diet in which animals receiving higher levels of DCBM required less time to ingest the same amount of DM (Hübner et al., 2008). This was confirmed by the time spent to consume 1 kg DM, which was influenced ($p < 0.05$) by the inclusion of castor bean meal, presenting reductions of 16 minutes for each unit of castor bean added.

Sheep ruminated for 533 min day^{-1} and this activity was not influenced ($p > 0.05$) by DCBM levels. Pires et al. (2009) also did not observe effect of additives in silages on the time spent ruminating min day^{-1}. Thus, although the inclusion of DCBM reduces NDF of the silages, which is related to the reduction in rumination time (Carvalho, Pires, Silva, Ribeiro, & Chagas, 2008; Carvalho, Pires, Silva, Veloso, & Silva, 2006), we suggest a compensatory effect due to the increase in NDF intake, a fact that kept the rumination activity unchanged in the treatments.

Time spent ruminating (minutes kg^{-1} DM and NDF) showed a linear decreasing effect ($p < 0.05$) with the inclusion of castor bean meal, which presented reduction of 20.71 and 28.12 minutes, per kg of DM and NDF, respectively, for each percentage unit of DCBM added to silage. As verified by Gomes et al. (2012), smaller dietary particles reduced the rumination time (min kg^{-1} of NDF) of sheep. Therefore, the present study proposed that the replacement of sugarcane by DCBM made the feed dry matter richer in concentrate particles, which were smaller, reflecting in the negative linear behavior of rumination times per unit of DM.

The inclusion of castor bean meal did not influence ($p > 0.05$) the number of rumen boluses per day, number of chews per day and per bolus, presenting mean values of 907.18 boluses, 50,898.12 chews day^{-1} and 58.9 chews $bolus^{-1}$, respectively (Table 4). Oliveira et al. (2018) also found no effect of additives on silage on the number of chews per bolus. However, the chewing time spent for each rumen bolus was quadratically influenced ($p < 0.05$) by the inclusion of castor bean meal, presenting a minimum point of 33.34 seconds $bolus^{-1}$ with 11.90% of castor bean meal. This fact indicates that although the animals presented the same number of chews per bolus, the addition of DCBM to the silage was able to influence the time in which this bolus remained in the sheep's mouth. This behavior can be justified by the reduction of the particle size with the inclusion of castor bean meal in the diet.

On average, sheep presented 19.0 feeding periods, 21.66 rumination periods and 35.76 resting periods and these variables were not influenced ($p > 0.05$) by DCBM inclusion (Table 5). This behavior was also documented by Carvalho et al. (2008) and Pires et al. (2009). Although the time of each period was obtained by dividing the total time obtained in 24 hours of observation, by the number of periods, the differences found in the time spent eating (14.70 min) and resting (17.97 min) were not able to influence ($p > 0.05$) times per periods.

Table 3. Dry matter intake (DMI) and neutral detergent fiber (CNDF), time spent eating, ruminating and resting of sheep fed sugarcane silage with detoxified castor bean meal.

Item	Level of castor bean meal (% NM)				Regression equation	CV (%)	R^2
	0	7	14	21			
	Intake						
DMI[1]	0.629	1.077	1.320	1.338	$Y = 0.6279 + 0.07998X + 0.00219X^2$	5,9	0,99
CNDF[1]	0.312	0.377	0.478	0.471	$Y = 0.3222 + 0.00846X$	6,4	0,88
	Minutes day^{-1}						
Eating	325.0	281.0	255.9	227.8	$Y = 319.596 - 4.51222X$	16,1	0,98
Ruminating	532.2	540.5	533.6	525.7	$Y = 533.02$	10,0	-
Resting	582.8	618.0	650.5	686.5	$Y = 582.915 + 4.90116X$	9,3	0,99
	Minutes kg^{-1} DM						
Eating	531.2	268.1	201.8	179.4	$Y = 459.191 - 16.0077X$	16,2	0,83
Ruminating	873.1	511.1	427.3	417.5	$Y = 768.772 - 20.7106X$	17,5	0,93
	Minutes kg^{-1} NDF						
Eating	1074.9	765.1	551.7	521.1	$Y = 1005.44 - 269.436X$	17,1	0,90
Ruminating	1764.9	1458.5	1169.7	1213.0	$Y = 1688.95 - 28.1219X$	15,7	0,86

1 kg day^{-1}, DM: dry matter; NDF: neutral detergent fiber; NM: natural matter.

Table 4. Number of ruminated boluses day^{-1}, time spent bolus^{-1}, number of chews bolus and number of chews day^{-1} of sheep fed sugarcane silage and detoxified castor bean meal.

Activity	Level of castor bean meal (%NM)				Regression equation	CV (%)	r^2
	0	7	14	21			
Boluses day^{-1}	758.4	1089.8	926.3	854.0	Y = 907.18	28.0	-
Time bolus^{-1} (sec)	42.81	32.6	35.6	37.5	$Y = 42.0044 - 1.44582X + 0.06063X^2$	17.4	0.80
Chews bolus^{-1}	63.5	53.8	57.3	61.0	Y = 58.91	19.8	-
Chews day^{-1}	47719	53995	51503	50727	Y = 50898.12	12.4	-

NM: natural matter.

Table 5. Mean values of number of feeding periods (NFP), rumination (NRP) and resting (NRRP), time spent eating (TSE), ruminating (TSR) and resting (TSRR) of sheep fed with sugarcane silage and detoxified castor bean meal.

Item	Level of castor bean meal (% NM)				Regression equation	CV (%)	r^2
	0	7	14	21			
NFP	20.22	20.30	17.64	17.86	Y = 19.00	18.0	-
NRP	21.00	21.20	22.73	21.71	Y = 21.66	21.2	-
NRRP	34.56	35.70	36.36	36.43	Y = 35.76	13.3	-
TSE (min)	16.95	14.06	14.77	13.04	Y = 14.70	24.8	-
TSR (min)	26.79	26.05	24.08	24.97	Y = 25.47	19.9	-
TSRR (min)	17.19	17.48	18.17	19.04	Y = 17.97	14.8	-

NM: natural matter.

Table 6. Intake of dry matter and neutral detergent fiber (grams meal^{-1}), feed and rumination efficiency (g MS and NDF hour^{-1}) and rumination (g of DM and NDF bolus^{-1}) of sheep fed sugarcane silage with castor bean meal.

Item	Level of castor bean meal (%NM)				Regression Equation	CV (%)	R^2
	0	7	14	21			
	Ingestion						
g DM meal^{-1}	32.33	54.42	73.25	72.83	Y = 37.4469 + 2.02399X	20.7	0.87
g NDF meal^{-1}	16.03	19.05	26.81	25.05	Y = 16.5365 + 0.509118X	21.8	0.78
	Feed efficiency						
g DM hour^{-1}	114.2	232.9	307.4	340.9	Y = 137.035 + 10.8074X	18.0	0.99
g NDF hour^{-1}	56.6	81.5	112.3	116.7	Y = 60.3533 + 3.04605X	17.5	0.98
	Rumination efficiency						
g DM hour^{-1}	69.69	119.14	142.67	148.71	Y = 33.6733 + 1.76430X	15.6	0.87
g NDF hour^{-1}	34.5	41.7	52.1	51.1	Y = 36.4848 + 0.83918X	15.7	0.86
	Rumination						
g of DM bolus^{-1}	0.84	1.08	1.40	1.57	Y = 0.845357 + 0.0361684X	25.2	0.99
g of NDF bolus^{-1}	0.42	0.38	0.51	0.54	Y = 0.383610 + 0.00740872X	25.2	0.72

DM: dry matter; NDF: neutral detergent fiber; NM: natural matter

The inclusion of DCBM promoted positive linear behavior ($p < 0.05$) on feeding and rumination efficiencies (g MS and NDF hour^{-1}) (Table 6). The intake of DM hour^{-1} increased by 10.80 g for each percentage unit of castor bean added in the silage. The addition of castor bean meal improved rumination efficiency, raising its values by 1.76 and 0.83 g of DM and NDF hour^{-1} for each unit of castor bean added. The addition of detoxified castor bean to silage promotes positive effects on rumination efficiency mainly by improving the silage fermentation pattern (Oliveira et al., 2015) and increasing the levels of residual carbohydrates in the silage. Ferreira et al. (2016) observed that the inclusion of dehydrated brewery residue improved the ingestion and rumination efficiencies of *U. brizantha* cv. Marandu.

The amount of ruminated DM and NDF bolus^{-1} increased as castor bean meal was added, presenting an increase of 0.036 and 0.007 g, respectively. For both DM and NDF values, this reflects the observed behavior for their intakes that increased as castor bean meal was added, since the number of boluses day^{-1} did not change, presenting a mean of 907.18.

Conclusion

The addition of detoxified castor bean meal to sugarcane silage reduces time spent eating and increases feed and rumination efficiency in sheep. It is recommended to add 21% of detoxified castor bean to sugarcane silage.

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