DOI: 10.5433/1679-0359.2016v37n3p1451

# Feeding behavior of lambs fed castor meal

# Comportamento ingestivo de cordeiros alimentados com farelo de mamona

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## Abstract

The experiment aimed to evaluate the feeding behavior of Santa Inês lambs fed diets containing different levels of detoxified castor meal in the concentrate. Twenty-four sheep with an average body weight of 18.5± 2.26 kg, at four months of age, were distributed in a randomized complete design with four treatment and six replications. Treatments consisted of four levels of castor meal (0, 33, 67, and 100%) replacing soybean meal. Animals underwent a 15-day adaptation period and an experimental period of 84 days. The diet was composed of 60% sugarcane silage and 40% concentrate, on a dry matter basis. Animal behavior (idle, rumination, and feeding activities) were observed visually for two 24-h periods with 5-min intervals, and recorded. The number of rumination chews and the time taken to ruminate each cud per day were counted using a digital stopwatch. Dry matter (DM) intake was not affected by inclusion of castor meal in the concentrate, averaging 884.02 g day$^{-1}$. The feeding activity was not affected by addition of castor meal. Rumination time increased linearly, whereas the idle and rumination times decreased linearly with addition of castor meal. Feeding time, expressed in min per kg of DM and NDF, was not influenced by the inclusion of the meal in the diet, averaging 373.3 and 880.0 min, respectively. The number of chews and the time taken to ruminate each cud were not changed by inclusion of castor meal in the diet. Feed efficiency, expressed in grams DM and NDF per hour, was not influenced by castor meal inclusion in the diet. Rumination efficiency expressed in g DM h$^{-1}$ decreased, but was not affected when expressed in g NDF h$^{-1}$. Total replacement of soybean meal by castor meal in the concentrate does not affect the feeding time or feed efficiency of feedlot sheep, but leads to a small reduction of their rumination efficiency. Thus, we recommend the inclusion of castor meal in sheep diets at the levels tested in this study.

**Key words**: Biodiesel by-products. Idleness. Feeding time. Rumination time.

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Recebido para publicação 16/05/14 Aprovado em 01/03/16

## Resumo

O experimento foi conduzido com o objetivo de avaliar o comportamento ingestivo de cordeiros da raça Santa Inês, recebendo dietas com diferentes níveis de farelo de mamona detoxificado no concentrado. Foram utilizados 24 ovinos, com peso corporal médio de 18,5± 2,26 kg e quatro meses de idade. Os animais foram distribuídos em delineamento inteiramente casualizado, com quatro tratamentos e seis repetições. Os tratamentos foram constituídos de quatro níveis de farelo de mamona (0, 33; 67 e 100%) em substituição ao farelo de soja. Os animais foram submetidos a um período 15 dias para adaptação e 84 dias de período experimental. A dieta foi constituída de 60% de silagem de cana-de-açúcar e 40% de concentrado, com base na matéria seca. As observações referentes ao comportamento animal foram realizadas de forma visual, durante dois períodos de 24 horas, a intervalos de 5 minutos. As variáveis comportamentais observadas e registradas foram: ócio, ruminação e alimentação. Foram realizadas a contagem do número de mastigações merícicas e a determinação do tempo despendido na ruminação de cada bolo ruminal, para cada animal, com a utilização de cronômetro digital. O consumo de matéria seca (MS) não foi afetado pela inclusão de farelo de mamona no concentrado apresentando valor médio de 884,02 g/dia. A atividade de alimentação não foi afetada com a inclusão de farelo de mamona. O tempo de ruminação apresentou efeito linear crescente, enquanto o de ócio ruminação apresentou efeito linear decrescente com a inclusão de farelo de mamona. O tempo de alimentação, expresso em minutos por kg de MS e FDN, não foi influenciado pela inclusão de farelo de mamona na dieta, apresentando valores médios de 373,3 e 880,0 minutos por kg de MS e FDN, respectivamente. O número de mastigações e o tempo gasto por cada bolo ruminado não foram alterados pela inclusão de farelo de mamona na dieta. A eficiência de alimentação, expressa de g de MS e FDN por hora, não foi influenciada pela inclusão de farelo de mamona na dieta. A eficiência de ruminação, expressa em g MS/hora, foi reduzida, enquanto a eficiência de ruminação, expressa em g FDN/hora, não foi afetada. A substituição total do farelo de soja pelo farelo de mamona no concentrado não afeta o tempo e a eficiência de alimentação de ovinos confinados, porém ocorre pequena perda de eficiência na ruminação. Desta forma recomenda-se a inclusão do farelo de mamona na dieta de ovinos nos níveis testado neste trabalho.

**Palavras-chave:** Coprodutos do biodiesel. Ócio. Tempo de alimentação. Tempo de ruminação.

## Introduction

The use of the feedlot for finishing sheep allows producers to supply better-quality diets to these animals, reducing the time necessary to reach slaughter weight. Unconventional feedstuffs, such as detoxified castor meal, need to be studied in ruminant feeding, since this is a good alternative whose potential has been little investigated. However, because the variability of nutritional content is larger in by-products than in conventional ingredients, frequent analyses of their chemical composition and of nutritional and productive parameters should be performed so that the obtained results can be better understood.

Government programs have fostered the use of the castor as biodiesel, aiming at the generation of clean energy. Increasing biodiesel production can be economically feasible if new applications are found for the by-products generated, such as the castor meal, since the current uses are not sufficient. From this perspective, its use in ruminant diets can be a viable option provided that safe levels for its use are established.

According to Costa et al. (2010), to achieve and maintain a certain level of consumption, ruminants are able to modify characteristics related to their feeding behavior in order to adapt to different feeding, management, and environmental conditions.

The study of the feeding behavior in ruminants can guide the adjustment of management practices, which can in turn provide increased productivity and ensure a better state of health and longevity to animals (FISCHER et al., 2002).

Characteristics inherent to these feedstuffs can interfere with the behavioral aspects displayed by animals. To better understand the daily feed intake, one must study its components individually, and these can be described by the number of meals consumed per day, by the average duration of meals, and by the feeding rate (speed) of each meal.

This study aimed to evaluate the feeding-behavior aspects of lambs receiving concentrate with different levels of castor meal.

## Materials and Methods

The experiment was conducted in the Experimental Laboratory for Cattle at Southwest Bahia State University, located in Itapetinga-BA, Brazil. Twenty-four intact Santa Inês male sheep with an average body weight of 18.5± 2.26 kg and at an average age of four months were distributed in a randomized complete design with four treatments and six replications. Prior to the beginning of the experiment, animals were dewormed and received injectable supplementation of vitamins A, D, and E, applied subcutaneously, and were kept in a feedlot with individual stalls and concrete floor equipped with feeder and drinker. Each stall had an area of 1.5 $m^2$, and all stalls were located inside the confinement shed, which was covered.

Four levels of replacement (0, 33, 67, and 100%) of soybean meal by detoxified castor meal in the concentrate were tested. Sugarcane treated with 0.5% micropulverized lime (CaO) (as-is basis) was used as roughage. Animals were subjected to a confinement period of 99 days, 15 of which were used for them to adapt to management, facilities, and diet, and the other 84 days were the actual experimental period (three 28-day periods).

The castor meal utilized in this study was acquired from an agribusiness in the metropolitan region of Salvador-BA, Brazil. The meal was detoxified previously with a micropulverized lime solution in which every kilogram was diluted into 10 L of water and applied in the amount of 60 g lime kg castor meal$^{-1}$ (as-is basis), as recommended by Oliveira et al. (2007). After the meal was mixed with the lime solution, the material remained at rest for a 12 h (overnight) and then it was dried on a cemented floor covered with canvas. The drying time was approximately 72 h.

Animals were fed a diet containing 60% sugarcane silage and 40% concentrate, on a dry matter basis. Diets were formulated to be isoproteic and provide a weight gain of 250 g day$^{-1}$, following NRC (2007). The four diets consisted of four levels of substitution of soybean meal for detoxified castor meal: 0, 33, 67, and 100%. Urea was utilized to adjust the crude protein concentration of the diets due to differences in the CP content of the protein feedstuffs (Table 1).

**Table 1.** Centesimal composition of experimental diets, on a dry matter basis.

| Ingredient[1] | Castor meal level (% DM) | | | |
|---|---|---|---|---|
| | 0 | 33 | 67 | 100 |
| Sugarcane silage | 60.00 | 60.00 | 60.00 | 60.00 |
| Corn | 16.99 | 17.36 | 16.77 | 16.32 |
| Soybean meal | 21.43 | 13.60 | 6.92 | 0.00 |
| Castor meal | 0.00 | 7.05 | 14.12 | 20.91 |
| Urea | 0.62 | 1.03 | 1.28 | 1.81 |
| Mineral mix[1] | 0.59 | 0.58 | 0.58 | 0.57 |
| Monoammonium phosphate | 0.37 | 0.38 | 0.34 | 0.38 |

[1] %DM = dry matter.

The chemical composition of silage, castor meal, concentrates, and complete rations was determined according to methodologies described by Silva and Queiroz (2002) (Table 2).

Lambs were received their feed daily, at 08h00 and 16h00, as a complete diet, which was adjusted daily according to the intake of the previous day, allowing 10% as refusals. The amount of feed supplied and refusals of each animal were weighed and sampled daily, and these samples were packed in labeled plastic bags and stored in a freezer. Samples were processed, packed, and transported to the Department of Animal Science of the Federal University of Viçosa, where the analyses were performed in the Laboratories of Forage Crops and Animal Nutrition, according to methodologies described by Silva and Queiroz (2002).

**Table 2.** Percentage of ingredients in diets and chemical composition.

| **Composition (%)** | Castor meal | Silage | Castor meal level (% DM) | | | |
|---|---|---|---|---|---|---|
| | | | 0 | 33 | 67 | 100 |
| Dry matter | 80.60 | 25.71 | 88.85 | 87.71 | 87.96 | 88.17 |
| Organic matter | 86.55 | 91.18 | 93.97 | 92.73 | 91.62 | 90.98 |
| Crude protein[1] | 33.73 | 2.96 | 33.95 | 34.64 | 33.60 | 33.62 |
| Ether extract[1] | 0.52 | 1.38 | 2.42 | 2.38 | 1.80 | 1.57 |
| Ash[1] | 13.45 | 8.82 | 6.03 | 7.27 | 8.38 | 9.02 |
| Total carbohydrates[1] | 50.72 | 86.84 | 57.60 | 55.71 | 56.22 | 55.79 |
| NDFap[1] | 30.10 | 61.76 | 14.47 | 18.89 | 23.42 | 25.34 |
| Non-fiber carbohydrates ap[1] | 20.62 | 25.08 | 43.14 | 36.82 | 32.80 | 30.45 |
| Estimated total digestible nutrients[2] | 56.43 | 56.59 | 78.48 | 69.90 | 61.80 | 57.21 |
| ***Diet components (%)*** | | | | | | |
| Dry matter | | | 50.97 | 50.51 | 50.61 | 50.70 |
| Organic matter | | | 92.30 | 91.80 | 91.35 | 91.10 |
| Crude protein | | | 15.36 | 15.63 | 15.22 | 15.22 |
| Ether extract[1] | | | 1.79 | 1.78 | 1.55 | 1.46 |
| Ash[1] | | | 7.70 | 8.20 | 8.65 | 8.90 |
| Total carbohydrates[1] | | | 75.14 | 74.38 | 74.59 | 74.42 |
| NDFap[1] | | | 42.84 | 44.61 | 46.42 | 47.19 |
| Non-fiber carbohydrates ap[1] | | | 32.30 | 29.77 | 28.16 | 27.22 |
| Estimated total digestible nutrients[2] | | | 65.33 | 61.68 | 58.09 | 55.87 |

[1] % DM; [2]Estimated according to NRC (2001); *NDFap = neutral detergent fiber corrected for ash and protein.

The LIPE® marker (purified, enriched lignin) (SALIBA et al., 2003) was used to estimate the fecal production, supplied daily at 08h00, for seven days, in a single dose of one capsule per animal, including three days for adaptation and regulation of the marker excretion flow and five days for feces collection.

For the estimate of voluntary roughage intake, we used the internal marker indigestible NDF (iNDF), obtained after rumen incubation for 240 h (CASALI et al., 2008) of 0.5 g of samples of silage, concentrates, refusals, and feces inside 5 × 5-cm non-woven fabric (TNT) bags with grammage 100 (100 $g.m^2$). The remaining material after incubation was subjected to extraction with neutral detergent for determination of the iNDF.

Dry matter intake (DMI) from the roughage was calculated as follows:

$$DMI\ (kg\ day^{-1}) = \frac{(FE \times (CMF - CMC))}{CMR}$$

where:

FE = fecal excretion (kg day$^{-1}$), obtained using LIPE®;

CMF = concentration of the marker in the feces (kg kg$^{-1}$);

CMC = concentration of the marker in the concentrate (kg kg$^{-1}$);

CMR = concentration of the marker in the roughage (kg kg$^{-1}$).

Dry matter intake from the concentrate was estimated using the marker chromium oxide, which was supplied in the amount of 5 g animal$^{-1}$ day$^{-1}$, mixed with the concentrate, divided into two applications, during 13 days, starting on the 39th experimental day. Feces were collected from the 48th to the 51st day directly from the rectal ampulla, and then pre-dried, ground, and gathered to form composite samples, as described previously.

Chromium was determined by acid digestion using nitric-perchloric acid (INCT-CA Method M-005/1), followed by filtering to obtain the solution in a volumetric flask, completing the volume to 50 mL. Later, an aliquot of the solution was transferred to polyethylene jars. The material was read on an atomic absorption spectrophotometer using a hollow-cathode lamp for chromium (357.9 nm wavelength) and nitrous oxide-acetylene flame in the Animal Nutrition Laboratory at DZO/UFV, following procedures described by Souza et al. (2012).

Analyses for the contents of dry matter (DM), ash, crude protein (CP), and ether extract (EE) in the samples of feeds, refusals, and feces were performed as described by Silva and Queiroz (2002). The organic matter (OM) content was estimated by subtracting the ash from the DM content. Neutral (NDF) and acid (ADF) detergent insoluble fiber (VAN SOEST et al., 1991) were analyzed on an autoclave, according to Pell and Schofield (1993).

Total carbohydrates (TC) were estimated according to Sniffenet al. (1992), as follows: TC = 100 - (%CP + %EE + %ash).

Concentrations of non-fiber carbohydrates corrected for ash and protein (NFCap) were calculated as proposed by Hall (2003): NFCap = (100 - %NDFap - %CP - %EE - %ash).

Total digestible nutrients (TDN) were calculated following Weiss (1999), but using NDF and NFC corrected for ash and protein, as shown in the equation below:

$$TDN\ (\%) = DCP + NDFap + DNFCap + (2.25 * DEE).$$

where:

DCP = digestible CP; DNDFap = digestible NDFap; DNFCap = digestible NFCap; and DEE = digestible EE.

The estimated total digestible nutrients content of feeds and total diets were calculated according to equations described by NRC (2001).

Observations referring to the animal behavior were performed visually, for a period of 24 h daily, during four days. Records were made every five minutes. During the night-time observation of animals, the environment was maintained under artificial lighting, to which the animals had been previously acclimated.

The behavioral variables observed and recorded were idleness, rumination, and time spent feeding. Feeding and rumination times were calculated as a function of DM and NDF intake (min kg DM$^{-1}$ or NDF$^{-1}$).

The number of rumination chews and the time spent on the rumination of each cud, for each animal, were counted using a digital stopwatch. To obtain the average number of chews and the time, three ruminal cuds were observed in three periods of the day (09h00-12h00, 15h00-18h00, and 19h00-21h00). To determine the number of daily cuds, the total rumination time was divided by the average time spent on the rumination of each cud, described previously, according to Bürger et al. (2000).

Time series discretization was performed directly on data-collection spreadsheets, by counting the discrete feeding, rumination, and idle periods. The duration of each discrete period was obtained by dividing the daily time of each activity by the number of discrete periods.

The variables g DM and NDF meal$^{-1}$ were obtained by dividing the average individual intake of each fraction by the number of feeding periods per day (in 24 h). Feed and rumination efficiency, expressed in g DM h$^{-1}$ and g NDF h$^{-1}$, was obtained by dividing the average daily intake of DM and NDF by the total time spent feeding and/or ruminating, in 24 h, respectively. The variables g DM and NDF cud$^{-1}$ were calculated by dividing the average individual intake of each fraction by the number of cuds ruminated per day (in 24 h), according to the methodology described by Bürger et al. (2000).

The data were interpreted by analysis of variance and study of regression by orthogonal contrasts, on the Statistical Analysis System (SAS, 2001). In the study of regression by orthogonal polynomials, for the choice of the models, we considered the significance, the coefficients of determination ($r^2$), and the behavior observed for the variable in question. The F test was used at a significance level of 5%.

## Results and Discussion

Daily dry matter (DM) intake was not affected (P = 0.503) by inclusion of castor meal in the concentrate (Table 3). Neutral detergent fiber (NDF) intake increased linearly (P=0.001) with inclusion of the meal in the diet, which is explained by the increase in the dietary NDF content from 14.59 to 25.34% (Table 2) with the addition of castor meal at the inclusion levels of 0 and 100%, respectively.

**Table 3.** Dry matter and neutral detergent fiber intake and times spent on feeding, rumination, and idle activities by lambs fed diets with detoxified castor meal.

| Item | Castor meal level (% DM) | | | | Regression equation | $r^2$ | SEM | Effect | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 33 | 67 | 100 | | | | L | Q | C |
| | Intake (g day$^{-1}$) | | | | | | | | | |
| DM | 892.4 | 910.3 | 874.9 | 858.5 | $\hat{Y}$ =884.0 | - | 12.53 | 0.226 | 0.497 | 0.523 |
| NDF | 338.4 | 378.6 | 390.8 | 400.0 | $\hat{Y}$ = 1 | 0.88 | 6.26 | <0.01 | 0.190 | 0.598 |
| | Min day$^{-1}$ | | | | | | | | | |
| Feeding | 307.2 | 320.7 | 320.2 | 336.0 | $\hat{Y}$ =321.02 | - | 5.14 | 0.062 | 0.909 | 0.509 |
| Rumination | 558.9 | 569.5 | 580.4 | 611.0 | $\hat{Y}$ = 2 | 0.93 | 6.76 | 0.005 | 0.449 | 0.741 |
| Idle | 573.9 | 543.0 | 533.3 | 486.9 | $\hat{Y}$ = 3 | 0.94 | 8.14 | <0.01 | 0.612 | 0.395 |
| | Min kg DM$^{-1}$ | | | | | | | | | |
| Feeding | 350.3 | 363.8 | 374.0 | 404.8 | $\hat{Y}$ = 373.3 | - | 9.55 | 0.063 | 0.649 | 0.779 |
| Rumination | 633.2 | 645.8 | 671.8 | 730.2 | $\hat{Y}$ = 4 | 0.94 | 13.13 | 0.016 | 0.372 | 0.867 |
| | Min kg NDF$^{-1}$ | | | | | | | | | |
| Feeding | 926.6 | 884.4 | 838.3 | 870.7 | $\hat{Y}$ = 880.0 | - | 22.85 | 0.214 | 0.419 | 0.689 |
| Rumination | 1674.6 | 1568.6 | 1505.5 | 1539.6 | $\hat{Y}$ =1572.0 | - | 31.15 | 0.085 | 0.186 | 0.771 |

Equations: $\hat{Y}_1 = 347.418 + 0.59087x$; $\hat{Y}_2 = 554.895 + 0.50193x$; $\hat{Y}_3 = 574.869 - 0.81240x$; $\hat{Y}_4 = 622.753 + 0.95104x$.

The time spent on the feeding activity was not influenced (P=0.268) by the levels of inclusion of castor meal, averaging 321.02 min. This behavior is a reflection of what occurred with DM intake, which displayed similar values between the treatments with inclusion of castor meal. This result is possibly explained by the similarity in particle size between the castor and soybean meals, which provided physical similarities between diets, not requiring a longer time for their ingestion.

There was an increase (P=0.001) in rumination activity, with maxima of 611.0 min achieved at the highest level of replacement. According to Van Soest et al. (1991), the rumination activity in adult animals takes approximately eight hours per day, with variations between four and nine hours. This behavior is mainly influenced by the characteristic of the diet, and seems to be proportional to the cell wall content of roughage feeds. With the increased inclusion of castor meal in the concentrate, the dietary NDF content rose from 14.47 to 25.34%, because this ingredient has a high NDF content and was added replacing the soybean meal. Therefore, higher levels of castor meal led to a longer rumination time, since the NDF is positively correlated with the time spent on this activity. This explanation can be verified by the increased rumination time per kilogram of DM consumed, which rose from 633.2 to 730.2 min for the castor meal levels of 0 and 100 g $kg^{-1}$ DM, respectively.

The reduction of the time spent by the animals on idle activities with the inclusion of castor meal can be explained by the exclusive nature of each one of the behavioral activities, thereby reflecting the complements to the feeding and rumination activities together.

Feeding time, expressed in min per kg DM and NDF, was not influenced (P=0.341 and P=0.552) by the inclusion of castor meal in the diet, averaging 373.3 and 880.0 min, respectively. This reflects the response observed for feeding time, which was also not altered, thereby showing that with the inclusion of castor meal the animals took the same time to consume equal amounts of DM or NDF.

Rumination, when expressed in min per kg of NDF, was not changed (P=0.240), averaging 1,572.0 min. This variable is affected by the particle size of the diets, since smaller feed particles pass through the rumen without the need for rumination. This fact explains the response observed in this study, as the castor meal used in the concentrate has a similar physical aspect to soybean meal. This results is similar to the 1,555.0 min obtained by Mendes et al. (2010), who utilized sugarcane bagasse as the main source of fiber in sheep diets.

The number of cuds ruminates per day, time spent per cud, number of chews per ruminated cud, and number of chews per day were not altered by inclusion of castor meal in the diet (Table 4). This response indicates that a slight elevation in the fiber content of the diet, near 5%, is not sufficient to increase the need for formation of cuds to be re-chewed, and that, once formed, they take the same time to be ruminated.

**Table 4.** Number of cuds ruminated per day, time spent per cud, number of chews per ruminated cud, and number of chews per day by lambs fed diets with detoxified castor meal.

| Activity | Castor meal level (% DM) | | | | Regression equation | SEM | Effect | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 33 | 67 | 10 | | | L | Q | C |
| Cuds $day^{-1}$ | 732.7 | 799.4 | 769.5 | 789.6 | $\hat{Y}$ = 772.80 | 14.65 | 0.286 | 0.429 | 0.267 |
| Time $cud^{-1}$ (s) | 46.8 | 43.3 | 47.1 | 47.7 | $\hat{Y}$ = 46.19 | 0.80 | 0.373 | 0.204 | 0.149 |
| Chews $cud^{-1}$ | 69.8 | 66.6 | 69.0 | 67.5 | $\hat{Y}$ = 68.21 | 1.09 | 0.636 | 0.702 | 0.340 |
| Chews $day^{-1}$ | 50492 | 52622 | 51007 | 52719 | $\hat{Y}$ = 51710 | 784.55 | 0.476 | 0.897 | 0.320 |

The daily feeding, rumination, and idle periods did not differ with the inclusion of castor meal levels, averaging 18.45, 22.26, and 33.09 periods, respectively (Table 5). This response can be explained by the similar nutritional composition of the diets, as Carvalho et al. (2008) asserted that the nutritional value of a diet has an influence on the number of periods of the behavioral activities.

**Table 5.** Mean values for number of periods per day and duration (minutes) of periods of behavioral variables of lambs fed diets with detoxified castor meal.

| Item[1] | Castor meal level (% DM) | | | | Regression equation | SEM | $r^2$ | Effect | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 33 | 67 | 100 | | | | L | Q | C |
| NFP | 18.87 | 20.09 | 18.13 | 16.71 | $\hat{Y}$ = 18.45 | 0.48 | | 0.058 | 0.165 | 0.378 |
| NRP | 22.57 | 23.64 | 22.38 | 21.92 | $\hat{Y}$ = 22.62 | 0.46 | - | 0.443 | 0.414 | 0.454 |
| NIP | 32.43 | 36.64 | 32.21 | 31.08 | $\hat{Y}$ = 33.09 | 0.64 | - | 0.128 | 0.134 | 0.333 |
| TFP | 17.11 | 17.09 | 18.83 | 21.60 | $\hat{Y}$ = 18.66 | 0.63 | - | 0.160 | 0.260 | 0.897 |
| TRP | 25.51 | 25.23 | 27.01 | 28.78 | $\hat{Y}_1$ | 0.61 | - | 0.035 | 0.401 | 0.701 |
| TIP | 18.05 | 15.26 | 17.12 | 16.52 | $\hat{Y}$ = 16.74 | 0.41 | 0.84 | 0.460 | 0.183 | 0.054 |

[1]Number of feeding (NFP), rumination (NRP), and idle (NIP) periods; time (duration) per feeding (NFP), rumination (TRP), and idle (TIP) periods
Equation: $\hat{Y}_1 = 24.2279 + 0.0347169x$.

The time spent per feeding and idle period was not changed (P>0.05) with the inclusion of castor meal, averaging16.66 and 16.74 min, respectively. The time spent per rumination period increased (P<0.05) by 0.034 min with every percent unit of castor meal added. This response can be explained by the increased NDF content in the diet with the addition of the meal, leading the animals to take more time in each behavioral station.

Dry matter intake (g meal$^{-1}$) was not affected (P=0.510) by inclusion of castor meal in the diet, whereas NDF intake (g meal$^{-1}$) increased linearly (P=0.0007) (Table 6). This result reflects the response observed for DM and NDF intake, since the number of meals for the tested levels of castor meal was the same: 18.45 meals (Table 5).

**Table 6.** Dry matter and neutral detergent fiber intake (g meal$^{-1}$), feed efficiency (g DM and NDF h$^{-1}$), rumination efficiency (g DM and NDF cud$^{-1}$) of lambs fed diets with detoxified castor meal.

| Item | Castor meal level (% DM) | | | | Regression equation | SEM | Effect | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 33 | 67 | 100 | | | L | Q | C |
| | Intake | | | | | | | | |
| g DM meal$^{-1}$ | 50.36 | 48.36 | 52.39 | 54.69 | $\hat{Y}$ = 51.45 | 1.68 | 0.264 | 0.526 | 0.609 |
| g NDF meal$^{-1}$ | 19.09 | 20.10 | 23.42 | 25.52 | $\hat{Y}_1$ | 0.77 | 0.001 | 0.716 | 0.597 |
| | Feed efficiency | | | | | | | | |
| g DM h$^{-1}$ | 177.24 | 175.18 | 170.72 | 158.42 | $\hat{Y}$ = 170.39 | 4.13 | 0.102 | 0.536 | 0.882 |
| g NDF h$^{-1}$ | 67.17 | 72.96 | 76.21 | 73.91 | $\hat{Y}$ = 72.56 | 1.85 | 0.161 | 0.279 | 0.856 |
| | Rumination efficiency | | | | | | | | |
| g DM /h$^{-1}$ | 97.43 | 97.06 | 91.24 | 85.42 | $\hat{Y}_2$ | 1.81 | 0.018 | 0.443 | 0.731 |
| g NDF /h$^{-1}$ | 36.93 | 40.37 | 40.72 | 39.77 | $\hat{Y}$ = 39.45 | 0.78 | 0.207 | 0.162 | 0.796 |
| | Rumination | | | | | | | | |
| g DM cud$^{-1}$ | 1.27 | 1.17 | 1.20 | 1.15 | $\hat{Y}$ = 1.19 | 0.034 | 0.312 | 0.728 | 0.531 |
| g NDF cud$^{-1}$ | 0.48 | 0.49 | 0.53 | 0.54 | $\hat{Y}_3$ | 0.015 | 0.016 | 0.925 | 0.544 |

Equations: $\hat{Y}_1 = 18.64418 + 0.067808x$. $r^2 = 0.97$; $\hat{Y}_2 = 99.0652 - 0.125554x$. $r^2 = 0.91$; $\hat{Y}_3 = 0.477312 + 0.000647x$. $r^2 = 0.87$.

Feed efficiency, expressed in grams of DM and NDF per hour, was not influenced (P=0.505 and P=0.328) by the inclusion of castor meal in the diet, averaging 170.39 and 71.56 g, respectively. The feed efficiency has a direct relationship with the levels of intake of nutrients by animals. Thus, the lack of a significant effect for the DM intakes might have contributed to the lack of relationships between feed efficiency in DM and the castor meal levels replacing soybean meal.

The rumination efficiency is an important variable in the assessment of the control of use of low-digestibility feeds, because the animal can ruminate a larger amount of feeds of this type, providing a greater feed intake and better productive performance. Rumination efficiency expressed in DM $h^{-1}$ decreased (P<0.001) by 0.12 g with every percent unit of castor meal included in the diet. The small reduction of rumination efficiency found in this study may be related to the increased dietary NDF content resulting from the addition of castor meal, leading to decreased efficiency in fiber use per unit time.

Rumination efficiency, expressed in NDF $h^{-1}$, was not affected (P=0.266) by addition of castor meal, averaging 39.45 g $h^{-1}$. This result is similar to that found by Costa et al. (2010), who, evaluating the inclusion of *Ziziphus joazeiro* hay in sheep diets, did not find alterations in rumination efficiency. This response is justified, because although NDF intake was increased by the inclusion of the meal in the diet, the time spent on the rumination activity also increased, which kept the rumination efficiency similar between treatments.

Rumination evaluated by the amount of DM per ruminated cud was not affected (P=0.671), averaging 1.19 g DM. However, when expressed as amount of NDF ruminated per cud, this variable increased with the inclusion of castor meal (P=0.001). This response is a consequence of that observed for the number of ruminated cuds (Table 4), which was not changed as castor meal was included, reflecting the behavior shown for DM and NDF intake.

## Conclusion

Total replacement of soybean meal by castor meal in the concentrate does not affect the feeding time or the feed efficiency of feedlot sheep, but it does cause a slight reduction of rumination efficiency. Therefore, we recommend the inclusion of castor meal in sheep diets at the levels tested in this study.

## Acknowledgments

To the National Council of Technological and Scientific Development (*Conselho Nacional de Desenvolvimento Tecnológico e Científico* - CNPq) and Southwest Bahia State University for the support in the research.

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