Ann. Anim. Sci., Vol. 18, No. 2 (2018) 469–482 *DOI: 10.1515/aoas-2017-0044*

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THE USE OF CASTOR MEAL, A BY-PRODUCT OF THE BIODIESEL INDUSTRY, IN A BEEF PRODUCTION SYSTEM IN TROPICAL PASTURES*

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Abstract

The objective of this study was to evaluate the impacts of castor meal, a by-product of the biodiesel industry, on growth performance and feeding behavior of heifers in a pasture production system in Northeast Brazil. Forty Holstein × Zebu crossbred heifers with an initial body weight of 257±26 kg were kept on a *Brachiaria decumbens* pasture under continuous grazing. The experiment lasted 140 days and was conducted in a completly randomized design with five levels of replacement of soybean meal with castor meal (0, 200, 500, 750, and 1000 g/kg of dry matter) in the supplements. Intake, digestibility, feeding behavior, performance, and carcass characteristics were evaluated. The total intakes of dry matter (DM), crude protein (CP), organic matter (OM), ether extract, and total digestible nutrients (TDN) decreased as the castor meal levels were increased. The digestibility coefficients of DM, CP, OM, and TDN decreased as the levels of castor meal in the supplement were increased. The castor meal levels in the supplement did not affect final body weight, average daily gain, feed conversion, hot carcass weight, or carcass dressing of the heifers. The use of supplements containing up to 1000 g/kg DM castor meal replacing soybean meal reduced the DM intake but did not change the average daily gain and feed efficiency of the heifers. Thus, the use of castor meal is a recommendable strategy to reduce production costs in a beef cattle grazing system.

Key words: alternative feedstuffs, by-product, heifers, performance, supplement

*This study was funded by FAPESB (Foundation for Research Support of the State of Bahia).

At present, the expansion prospects of the Brazilian cattle herd associated with the strong international demand will keep the Brazilian beef highly competitive in the world market. In this scenario, the intensification of pastoral production systems is pointed as one of the sustainable-exploitation alternatives, as it reduces the need for opening new areas for agricultural production (Barcellos et al., 2008). In this regard, the association of pastures and concentrate supplements, in intensified systems, allows for an increase in number of animals per area unit as well as an improvement in performance so that these animals can be slaughtered earlier (Cabral et al., 2014).

Concentrate supplements, however, are expensive. Thus, alternative feedstuffs, such as those generated from the biodiesel industry, may represent viable options. Among the by-products with potential for use in ruminant diets is the castor meal, a high-protein (38%; Nicory et al., 2015 a) ingredient. In trials with small ruminants (Menezes et al., 2015; Nicory et al., 2015 b), dairy cows (Cobianchi et al., 2012) and finishing cattle (Diniz et al., 2011), the castor meal was efficient in replacing the protein from traditional concentrates. On the other hand, a recent study (Palmieri et al., 2016) showed that castor meal compromised the animal performance of goat kids.

These controversial situations indicate that research results should not to be extrapolated to situations different from those tested and that there is a need for further research to accurately define the limits of use of castor meal in diets for ruminants in different production systems. Therefore, we hypothesized that the replacement of soybean meal by castor meal supplements for heifers in tropical pastures does not reduce the nutritional and productive performance of the animals, representing an alternative in reducing feed costs.

Given the dearth of information and the need for consolidating the responses to the use of castor meal in supplementation provided on pasture, this work aimed to investigate the impact of this feedstuff on the production performance and feeding behavior of heifers in a pasture-based production system.

Material and methods

The experiment was conducted in the beef cattle unit of the Center for Agricultural, Environmental, and Biological Sciences of Federal University of Recôncavo da Bahia, located in Cruz das Almas-BA, Brazil (12º40'39" S latitude, 39º06'23" W longitude, and 225.87 m altitude). The meteorological data were collected at the meteorological station of Brazilian Agricultural Research Corporation, Cassava and Fruticulture, in Cruz das Almas-BA, Brazil.

Animals, experimental design, and diets

The experiment lasted 140 days in total, and the first 14 days were used as an adaptation period. Forty Holstein × Zebu crossbred heifers with an average initial body weight (BW) of 257±26 kg were distributed in a completely randomized design with five treatments (groups) and eight replications (animals). Heifers were kept on a *Brachiaria decumbens* pasture under continuous grazing. The treatments corresponded to the experimental supplements formulated with castor meal replacing soybean meal at the levels of 0, 200, 500, 750, and 1000 g/kg of dry matter (DM) (Table 2). The castor meal was acquired from an agro-industry company of the metropolitan region of Salvador-BA. The chemical composition of the pasture and experimental supplements is presented in Table 1.

Table 1. Chemical composition of the pasture and experimental supplements with castor meal

Item (g/kg DM)	Pasture	Castor meal replacing soybean meal (g/kg DM)				
		0	200	500	750	1000
Dry matter[a]	602	881	878	878	881	883
Organic matter	921	961	954	953	947	937
Crude protein	150	228	238	218	217	218
Ether extract	34.0	58.0	48.0	49.0	30.0	40.0
Neutral detergent fiber[b]	62.0	29.5	30.1	28.9	29.9	33.9
Non-fiber carbohydrates	116	329	284	330	288	300
Indigestible neutral detergent fiber	174	41.0	63.0	86.0	109	149
Total digestible nutrients	-	706	678	662	675	660

[a]In g/kg fresh matter.
[b]Corrected for ash and protein.

Table 2. Proportion of ingredients (g/kg DM) of experimental supplements with castor meal

Item (g/kg DM)	Castor meal replacing soybean meal (g/kg DM)				
	0	200	500	750	1000
Ground corn	712	672	720	707	693
Soybean meal	254	238	125	66	0
Castor meal	0	60	125	197	277
Urea	15	15	15	15	15
Mineral salt[a]	12	12	12	12	12
Dicalcium phosphate	3	3	3	3	3

[a]Compositions in each 100 g: sodium chloride (NaCl) – 47.15 g; dicalcium phosphate – 50.00 g; zinc sulfate – 1.50 g; copper sulfate – 0.75 g; cobalt sulfate – 0.05 g; potassium iodate – 0.05 g; magnesium sulfate – 0.50 g.

Due to the presence of ricin in castor meal commonly found in this biodesel byproduct, before the supply to the animals the detoxification of the meal through the use of a solution of calcium oxide $Ca(OH)_2$ was caried out. Thus, castor meal was diluted in water (10 L of water for each kg of $Ca(OH)_2$ in ratio of 60 g $Ca(OH)_2$/kg of meal, as recommended by Anandan et al. (2005). The ricin was qualitatively, and the eletrophoresis was performed with the following conditions. At first, there was the separation of fractions A (36 kDa) and B (29 kDa) polyacrylamide gel at 12% under denaturing conditions (SDS-PAGE; Laemmli, 1970). Then for processing, the gel was placed in solution with 0.1% Coomassie blue. In order to visualize the protein bands on the gel there were stained with a 40% methanol solution containing 10% acetic acid. The molecular weights of the bands stained with ricin extracts were determined using known molecular weight markers (Sigma, USA). The detoxification treatment of the castor bean meal was considered effective when there were no visible bands in the standard ricin gels (Figure 1).

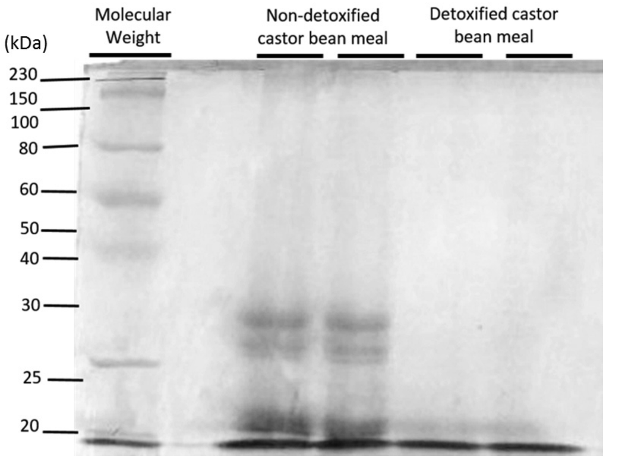

Figure 1. Polyacrylamide gel electrophoresis of castor meal detoxified or non-detoxified with $Ca(OH)_2$. The ricin was evaluated qualitatively by the separation of fractions A (36 kDa) and B (29 kDa) polyacrylamide gel at 12% under denaturing conditions in solution with 0.1% Coomassie blue. Molecular weights of the stained ricin bands extracted in the meals were determined using markers of known molecular weight and the treatment of castor meal was considered effective due to no visible ricin bands in the standard gels

Heifers were weighed at the beginning and end of the experiment and every 21 days to adjust the feed supply. Before each weighing, heifers were fasted for 12 h to evaluate the body weight gain (BWG). Animals were identified, dewormed, and moved to a 35 ha area divided into five 7 ha paddocks where they remained during the entire experimental period and were given free access to water and supplement, which was supplied daily in uncovered plastic troughs at 1100 h in the proportion of 0.7 kg/100 kg of the BW for all supplemented animals.

Diets were formulated to meet all requirements for maintenance and provide a BWG of 1.0 kg/day according to NRC (2000). To reduce the influence of biomass variation between paddocks, heifers were kept in each paddock for seven days, and after this period, they were transferred to another one at random. The pasture was evaluated on the 14th, 77th, and 140th days of the experiment to estimate the availability of DM. Twelve samples were obtained per paddock by cutting the grass near the soil level using a 0.25-m^2 square frame.

Intake and digestibility evaluations

Dry matter intake (DMI), digestibility, and fecal production were estimated using three markers: an internal type (indigestible neutral detergent fiber, iNDF), two external-type markers (LIPE® and titanium dioxide). Two feces collection periods were held on the 42nd and 84th days of experiment. To estimate fecal DM excretion, one marker in capsule form containing 500 mg of purified and enriched lignin (LIPE®) was supplied daily for seven days. The first two days of each collection period were used for adaptation, and the remaining five days were used for feces collection (Saliba et al., 2000). The fecal DM excretion data were used to obtain the digestibility estimates and the DMI from the pasture.

During the collection period, animals were led to a restraining barn, where fecal samples were carefully collected directly from each animal to avoid contaminating the feces for five days. For pre-drying, the samples were thawed, weighed, and dried in a forced-air oven at 55ºC for 72 h. Samples of the feces from all animals were sent to the Nutrition Laboratory of the Veterinary School of UFMG for estimates of fecal production determined via the use of LIPE® in an infrared spectrometer.

To estimate the DMI from the supplement (DMIS), titanium dioxide (TiO_2) was used as a marker, supplied in the amount of 10 g per animal mixed with the supplement daily for eight days. Titanium dioxide was determined by Myers et al. (2004). The supplement intake was calculated as follows:

$$DMIS = (FE \times TiO_2\,feces)/TiO_2\,supplement$$

where: TiO_2 feces and TiO_2 supplement refer to the concentrations of titanium dioxide in the feces and in the supplement, respectively. The total DMI was estimated using iNDF, which is an internal marker obtained after ruminal incubation, for 240 h (Casali et al., 2008), and DMI was calculated as follows:

$$TDMI\ (kg/day) = [FE \times CMF) - iNDFS]/CMR + DMIS$$

where: *FE* = fecal excretion (kg/day) obtained using LIPE®, *CMF* = the concentration of iNDF in the feces (kg/kg), *CMR* = the concentration of marker in the roughage (kg/kg), *iNDFS* = the amount of iNDF in the supplement, and *DMIS* = DMI from the supplement.

For the grazing simulation, forage samples were collected in two five-day periods from the 41st to the 45th and from the 83rd to the 87th experimental days, as described by Johnson (1978).

Chemical analyses

Chemical analyses of forage samples, supplements, and feces were performed in the Animal Nutrition Laboratory at Southwest Bahia State University, in Itapetinga-BA, Brazil. Samples were pre-dried in a forced-air oven at 55ºC for 72 h. Next, they were processed in a Wiley mill with a 1-mm sieve. DM, crude protein (CP), ether extract (EE), and mineral matter (MM) contents were determined according to AOAC (1990) Method 934.01 for DM, Method 981.10 for CP, Method 920.39 for the EE, and Method 930.05 for MM. For the analysis of the neutral detergent fiber corrected for ash and protein (NDFap), samples were treated with heat-stable alpha-amylase without the use of sodium sulfite and corrected for the ash residue (Mertens, 2002) and the residual nitrogen compounds (Licitra et al., 1996). Non-fiber carbohydrates (NFC) were estimated using the formula proposed by Hall (2000). Total digestible nutrients (TDN) were calculated according to Weiss (1999).

Feeding behavior evaluation

To evaluate the feeding behavior, animals were observed visually for 24 h before and after each period of the supply of the markers. During the night period, observations were made using flashlights in 5-min intervals. Information about the times spent grazing, feeding at the trough, ruminating, and performing other activities was collected. Grazing time was considered the time spent on the activities of search and selection of forage in the pasture with the animal on ingestion activity (Mezzalira et al., 2011). Other activities were characterized as the periods during which the animal was not grazing, drinking water, consuming supplement, or ruminating.

Performance and carcass characteristics evaluations

At the end of the experiment, the animals were sent to a commercial abattoir in Feira de Santana BA, Brazil, for slaughter. Before slaughter, they were fasted for 12 h and weighed. Immediately after slaughter, carcasses were identified and weighed to obtain the weights and hot carcass yields. Next, they were chilled for 24 h at 2ºC and weighed again to determine the cold carcass weights and yields. After cooling, the carcass was sectioned into two parts. The right side was used to evaluate the following quantitative characteristics of the carcass according to Müller (1980): conformation, leg length (LL), round thickness (RT), and carcass length (CL). After these measurements, a section was made between the 12th and 13th ribs to expose the transverse section of the *Longissimus dorsi* muscle to evaluate its color, marbling, and texture.

The carcass conformation was determined by a subjective evaluation that considered the muscle development (the fat cover was excluded from the calculations), and higher values correspond to better conformations. In this evaluation, the muscle development, excluding the fat cover, was considered according to the scale of points described by Müller (1980). A tape measure was used in the evaluation of CL. The distance from the anterior edge of the pubic bone to the medial cranial edge of the first rib was measured. LL was measured with a wooden compass with metal ends as the distance between the anterior edge of the pubic bone and the midpoint of the bones of the tarsal joint. Subsequently, this distance was measured with a tape measure. Similarly, the RT was obtained by measuring the distance between the lateral face and the midpoint of the upper portion of the round.

The fat cover degree (FCD) was determined as the average of three measurements obtained at equidistant points using a precision caliper in the region of the cut between the 12th and 13th ribs over the *Longissimus dorsi* muscle. The loin-eye area (LEA) was measured using a gridded plastic planimeter with a point in the middle of each square with each square representing 1/10 of a square inch. Marbling was determined based on the intramuscular fat observed in the *longissimus* muscle between the 12th and 13th ribs according to the scoring system suggested by Müller (1980). Color was determined considering the color of the muscle after the carcasses were chilled for 24 h. A transverse section was made on the *longissimus* muscle in the region between the 12th and 13th ribs, and after 30 min, the meat was evaluated according to the scale of points described in Müller (1980). Texture was measured based on the size of the fascicles (grains of muscle) and evaluated subjectively with a point scale by observing the same region used for the evaluation of marbling.

Statistical analysis

Data were subjected to analysis of variance, interpreted through decomposition of the orthogonal polynomials into linear and quadratic using the PROC GLM function of the SAS software (2004), according to the model below:

$$Yijk = m + Ti + eijk$$

where: *Yijk* = observed value of the variable, *m* = overall constant, *Ti* = effect of treatment i, and *eijk* = the error associated with each observation.

All statistical procedures were performed using the value of 0.05 as the critical level of probability for error type I.

Results

In the present study, the average DM production per hectare was 3,900 kg, which provided an average forage allowance in relation to BW of 11.5 kg/100 kg. The daily total DMI expressed as kg/100 kg of BW was not influenced by the replacement of the soybean meal with castor meal ($P>0.05$), averaging 2.1 kg/100 kg DM BW (Table 3). However, the intake calculated as a percentage of metabolic weight decreased linearly ($P<0.05$) with the inclusion of castor meal in the supplement because the total dry matter (TDM) intake was also influenced ($P<0.05$) by the level of castor meal, decreasing linearly (Table 3).

The intakes of CP, OM and NDF from the pasture decreased linearly ($P<0.05$) as the levels of castor meal in the supplement were increased (Table 3). The intake of NFC decreased linearly ($P<0.05$) as the levels of castor meal were increased (Table 3). Total intakes of DM, CP, NDF, OM, EE, total carbohydrates (TC), and TDN decreased as the levels of castor meal in the supplement were increased ($P<0.05$); additionally, castor meal levels had no effect ($P>0.05$) on the total NFC intake (Table 3). The digestibility coefficients of DM, CP, OM, TC, and TDN decreased linearly ($P<0.05$) with the levels of castor meal, but the castor meal levels did not influence ($P>0.05$) the digestibility coefficients of NDFap or NFC (Table 4).

There was no effect of castor meal level ($P>0.05$) on final body weight (FBW), BWG, feed conversion (FC), hot carcass weight (HCW), or carcass dressing (CD) of the heifers (Table 5). The levels of castor meal had no effect ($P>0.05$) on CL, LL, or round thickness (RT) (Table 5). Conformation and loin-eye area (LEA) were not affected ($P>0.05$) by the castor meal levels (Table 5). The replacement of soybean meal with castor meal had a linear effect ($P<0.05$) on FCD, which decreased with the inclusion of this by-product in the supplement (Table 5). In this study, the average FCD was 3.95 mm. The meat texture, marbling, and color were similar ($P>0.05$) among the groups fed the different supplements (Table 5).

Table 3. Intake of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), neutral detergent fiber corrected for ash and protein (NDFap), non-fibrous carbohydrates (NFC), total carbohydrates (TC) and total digestible nutrients (TDN) from pasture, supplements, and total, by the heifers on pasture receiving supplement containing castor meal replacing soybean meal

Item	Castor meal replacing soybean meal (g/kg DM)					SEM	P-value	
	0	200	500	750	1000		L	Q
Intake (kg/day)								
DM pasture	5.13	4.97	4.82	4.80	4.22	0.08	<0.01	0.37
DM supplement	2.27	2.00	2.09	2.16	1.98	0.07	0.37	0.64
total DM intake	7.40	6.97	6.89	6.96	6.20	0.09	<0.01	0.66
OM pasture	4.76	4.60	4.45	4.43	3.88	0.07	<0.01	0.36
OM supplement	2.19	1.91	1.98	2.03	1.84	0.06	0.24	0.67
total OM	6.95	6.52	6.43	6.47	5.72	0.09	<0.01	0.63
CP pasture	0.78	0.79	0.68	0.68	0.63	0.01	<0.01	0.86
CP supplement	0.52	0.48	0.45	0.47	0.43	0.01	0.10	0.66
total CP	1.30	1.27	1.37	1.15	1.06	0.02	<0.01	0.79
EE pasture	0.15	0.16	0.17	0.16	0.17	0.01	0.16	0.31
EE supplement	0.13	0.09	0.10	0.06	0.08	0.01	<0.01	0.03
total EE	0.28	0.26	0.27	0.22	0.25	0.01	<0.01	0.28
NDFap pasture	3.23	3.07	2.99	3.01	2.56	0.05	<0.01	0.34
NDFap supplement	0.66	0.61	0.61	0.65	0.67	0.02	0.81	0.25
total NDFap	3.89	3.69	3.69	3.67	3.24	0.05	<0.01	0.62
NFC pasture	0.59	0.49	0. 52	0.65	0.52	0.01	0.69	0.24
NFC supplement	0.88	0.73	0.82	0.80	0.63	0.02	0.04	0.67
total NFC	1.47	1.22	1.34	1.45	1.15	0.02	0.05	1.00
TC pasture	3.84	3.58	3.61	3.58	3.11	0.06	<0.01	0.45
TDN	5.20	4.68	4.55	4.73	4.07	0.08	<0.01	0.82
Intake (kg/100 kg BW)								
total DM	2.27	2.16	2.15	2.21	1.91	0.05	0.01	0.54
NDF	1.19	1.14	1.13	1.17	1.00	0.03	0.11	0.55
TDN	1.59	1.45	1.42	1.50	1.26	0.03	0.03	0.85
Intake (kg/100 kg BW)^{0,75}								
total DM	9.62	9.13	9.10	9.30	8.12	0.16	0.04	0.51

L = Linear effect. Q = Quadratic effect. SEM = Standard error of the mean.

DM pasture: $\hat{Y} = 5.186 - 0.008x$, $R^2 = 0.83$; Total DM: $\hat{Y} = 7.366 - 0.0096x$, $R^2 = 0.77$; OM pasture: $\hat{Y} = 4.81 - 0.0077x$, $R^2 = 0.84$; Total OM: $\hat{Y} = 6.92 - 0.01x$, $R^2 = 0.80$; CP pasture: $\hat{Y} = 0.794 - 0.0016x$, $R^2 = 0.86$; Total CP: $\hat{Y} = 1.35 - 0.0024x$, $R^2 = 0.58$; EE supplement: $\hat{Y} = 7E - 06x^2 - 0.0012x + 0.1299$, $R^2 = 0.81$; Total EE: $\hat{Y} = 0.276 - 0.0004x$, $R^2 = 0.47$; NDF pasture: $\hat{Y} = 0.846 - 0.0011x$, $R^2 = 0.75$; Total NDF: $\hat{Y} = 0.93 + 0.0009x$, $R^2 = 0.76$; NFC supplement: $\hat{Y} = 0.858 - 0.0017x$, $R^2 = 0.50$; TDN: $\hat{Y} = 5.088 - 0.0088x$, $R^2 = 0.74$.

The evaluation of the feeding-behavior activities revealed quadratic effects (P<0.05) of the level of castor meal on the times spent grazing, feeding at the trough, and performing other activities, and linear increase in the frequency of intake (FQI) and frequency of other activities (FQO; P<0.05). Minimum responses of 469.1 min and 25.7 min and a maximum value of 524.252 min were observed for the castor meal levels of 105.7, 66.1, and 348.6 g/kg DM, on times spent grazing, feeding at the trough, and performing other activities, respectively (Table 6). Notable increases were observed in the times spent grazing and feeding at the trough as the level of soybean meal replaced with castor meal was increased.

Table 4. Digestibility coefficients of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), neutral detergent fiber corrected for ash and protein (NDFap), non-fibrous carbohydrates (NFC), and total digestible nutrients (TDN) of heifers on pasture receiving supplements containing castor meal replacing soybean meal

Item	Castor meal replacing soybean meal (g/kg DM)					SEM	P-value	
	0	200	500	750	1 000		L	Q
DM	0.71	0.69	0.66	0.67	0.65	0.30	<0.01	0.21
OM	0.74	0.72	0.69	0.70	0.68	0.31	<0.01	0.33
CP	0.77	0.77	0.73	0.73	0.73	0.44	<0.01	0.39
EE	0.56	0.53	0.59	0.44	0.52	1.07	0.11	0.96
NDFap	0.63	0.62	0.60	0.63	0.60	0.72	0.57	0.94
NFC	0.93	0.90	0.89	0.93	0.91	0.60	0.90	0.20
TDN	0.70	0.67	0.66	0.68	0.66	0.47	0.02	0.20

L= Linear effect; Q= Quadratic effect.
DM: $\hat{Y} = 70.072 - 0.0555x$, $R^2 = 0.84$.
OM: $\hat{Y} = 73.274 - 0.0534x$, $R^2 = 0.83$.
CP: $\hat{Y} = 77.146 - 0.0494x$, $R^2 = 0.72$.
TDN: $\hat{Y} = 68.916 - 0.0322x$, $R^2 = 0.52$.
SEM = Standard error of the mean.

Table 5. Performance parameters of heifers on pasture receiving supplements containing castor meal replacing soybean meal

Item	Castor meal replacing soybean meal (g/kg DM)					SEM	P-value	
	0	200	500	750	1 000		L	Q
Initial body weight (kg)	262.3	259.5	257.6	255.2	252.6	-	-	-
Final body weight (kg)	379.8	382.3	373.0	363.1	374.0	7.37	0.58	0.84
Average daily gain (g/d)	932.5	974.9	917.9	857.1	963.5	0.03	0.79	0.68
Feed conversion (kg DM/kg BWG)	8.0	7.4	7.6	8.4	6.1	0.23	0.17	0.25
Hot carcass weight (kg)	188.7	186.4	178.3	180.2	183.4	4.14	0.54	0.57
Carcass dressing (%)	49.7	48.8	47.7	49.7	49.1	0.35	0.87	0.21
Carcass length (cm)	134.2	137.8	136.4	135.2	136.0	0.96	0.85	0.45
Leg length (cm)	70.0	68.2	71.2	70.4	71.6	0.77	0.32	0.67
Round thickness (cm)	24.8	24.3	23.0	23.6	24.2	0.42	0.46	0.26
Conformation (points)	14.2	14.5	14.2	14.2	14.4	0.14	0.87	0.96
Loin-eye area (cm^2)	60.3	59.2	58.8	59.8	61.4	0.83	0.67	0.33
Fat cover degree (mm)	5.2	4.5	4.3	4.2	2.8	0.27	0.01	0.59
Marbling (points)	5.5	5.3	7.4	7.0	6.2	0.26	0.08	0.12
Texture (points)	4.0	3.8	3.8	3.8	4.2	0.08	0.54	0.08
Color (points)	4.2	4.2	3.6	4.4	4.4	0.11	0.37	0.13

L= Linear effect; Q= Quadratic effect.
Fat cover degree: $\hat{Y} = 5.242 - 0.0207x$, $R^2 = 0.83$.
SEM = Standard error of the mean.

There was no influence of castor meal (P>0.05) on the percentages of rumination (PRM), lying (PLY), and other activities. The use of castor meal replacing soybean meal in the supplement influenced (P<0.05) the times spent feeding, idle, and performing other activities; these times decreased linearly (Table 6). No significant differences (P>0.05) were detected for the time spent ruminating (RUM) or frequency of rumination (FR), whereas time per rumination period (TRP) increased (P>0.05).

Table 6. Times spent grazing (GRZ), feeding at the trough (TRH), ruminating (RUM), and performing other activities (OTH); percentage of rumination (PRM); percentage of lying idle behavior (PLY); frequencies of intake (FQI), rumination (FQR), and other activities (FQO); time per feeding period (TFP); time per rumination period (TRP); and time per period spent on other activities (TOP) by heifers on pastures receiving supplements containing castor meal replacing soybean meal

Item	Castor meal replacing soybean meal (g/kg DM)					SEM	P-value	
	0	200	500	750	1 000		L	Q
GRZ (min)	474.8	470.0	453.6	545.7	528.4	4.65	<0.01	0.05
TRH (min)	27.5	24.3	27.0	41.4	42.0	0.84	<0.01	0.01
RUM (min)	399.2	433.4	387.3	340.4	407.9	7.16	0.14	0.24
OTH (min)	538.5	512.3	572.1	512.5	461.8	7.54	0.01	0.01
PRM (%)	77.4	86.5	87.8	74.3	87.0	1.12	0.47	0.49
PLY (%)	53.5	56.5	51.7	46.6	54.3	0.99	0.24	0.26
FQI (number)	14.1	12.1	15.4	22.0	17.3	0.44	<0.01	0.48
FQR (number)	14.8	16.4	15.4	13.4	17.4	0.26	0.26	0.08
FQO (number)	26.0	25.0	28.3	31.0	28.7	0.43	<0.01	0.33
TFP (min)	36.3	40.3	32.1	27.3	32.6	0.83	<0.01	0.33
TRP (min)	27.9	27.3	25.4	26.1	23.9	0.45	0.01	0.84
TOP (min)	21.5	20.9	20.6	17.5	16.4	0.30	<0.01	0.17

L = Linear effect; Q = Quadratic effect
GRZ: $\hat{Y} = 469.124 - 0.19777x + 0.00935915x^2$, $R^2 = 0.59$;
TRH: $\hat{Y} = 25.7477 - 0.0283979x + 0.00214686x^2$, $R^2 = 0.82$;
OTH: $\hat{Y} = 524.252 + 1.37483x - 0.0197183x^2$, $R^2 = 0.67$;
FQI: $\hat{Y} = 12.8516 + 0.0658839x$, $R^2 = 0.46$;
FQO: $\hat{Y} = 25.4688 + 0.0463214x$, $R^2 = 0.57$;
TFP: $\hat{Y} = 37.879 - 0.0824617x$, $R^2 = 0.43$;
TRP: $\hat{Y} = 27.9431 - 0.0362636x$, $R^2 = 0.83$;
TOP: $\hat{Y} = 22.157 - 0.0554165x$, $R^2 = 0.90$.
SEM = Standard error of the mean.

Discussion

According to the National Research Council (NRC, 1996), pastures with less than 2000 kg DM per hectare result in lower pasture intake and longer grazing times. The percentage of leaves decreased from 39.96% to 12.24% from 17 November 2011 to 9 April 2014, which resulted in a reduction of the leaf:stem ratio, whose values for each period were 1.20, 0.69, and 0.45, respectively. The daily total DMI expressed as kg/100 kg of BW averaged 2.1 kg/100 kg DM BW, which is close to the 2.2 kg/100 kg DM BW found by Almeida et al. (2014) in animals consuming supplement in the proportion of 0.7 kg/100 kg of their BW.

The reduction of the castor meal level in the composition of the supplement probably resulted in an increase in the amount of TDN in terms of percentage of body weight and better synchronism between the availability of energy and ammonia in the rumen (carbon/nitrogen ratio), which increased microbial protein synthesis and digestion and ultimately led to greater intake (Moore et al., 1999). The results obtained for pasture DMI in this study are similar to those found by Barros et al. (2011), who evaluated the replacement of soybean meal with detoxified castor meal in supplements for grazing heifers and found an average DMI of 5.41 kg/d for this variable. The reduced intakes of CP, OM, and NDF may be attributed to the lower DMI from the pasture because all these components are part of this fraction.

Intakes of DM, CP, OM, and NDF from the supplement did not vary, which may have been related to the balancing of these supplements, which were formulated to be isonitrogenous and to have similar OM and TC compositions. Additionally, the supplements were completely consumed by the animals. The intake of NFC decreased linearly as the levels of castor meal were increased as a result of the composition of the supplements because the supply was limited to 0.7 kg/100 kg of the body weight, and there were no refusals in the trough.

A large portion of the decreases in total intakes of DM, CP, NDF, OM, EE, TC, and TDN is a reflection of the reduction of pasture intake, which averaged 69.5% of the total feed consumed by the animals. Furthermore, because there was a decrease in the digestibility of DM when the level of castor meal in the supplement was increased, fermentation was slower, which extended the residence time of the feed in the rumen and reduced DMI. The lower energy input from the diets containing castor meal likely decreased the synchronism and consequently the synthesis of microorganisms in the rumen.

In a study with finishing feedlot cattle, Diniz et al. (2011) utilized an *in situ* trial to demonstrate a reduction of the rumen degradability of DM when castor meal was treated with calcium oxide, which may explain the decrease in the apparent digestibility of the total DM found in this study as the level of castor meal in the supplements was increased. The effective rumen degradation of the CP from castor meal is much lower than that from soybean meal (Moreira et al., 2003). Despite the lower energy intake obtained with the inclusion of castor meal in the supplement, microbial synthesis was sufficient to maintain the digestibility of the NDFap and NFC from the supplements. Because the forage and supplement had low EE contents and did not provide high levels of EE intake, there was no effect on the EE digestibility coefficient, whose mean value was 0.53, which is lower than the 0.75 found by Diniz et al. (2011).

The average BWG (0.93 kg/day) was very close to the desired goal, which was to meet the maintenance and gain requirements of 1.0 kg/day. Despite the significant reduction of total DMI discussed previously, this decrease was not sufficient to alter the BWG by the animals and thus resulted in similar FBW (average 374.4 kg) and consequently did not generate variations in the HCW. Despite the greater fiber content of the castor meal, this by-product was found to be efficient for replacing soybean meal, which is a traditional, high-cost ingredient used in ruminant diets. The results of this study revealed a behavior similar in the feed conversion to that observed by Barros et al. (2011) who also evaluated castor meal in cattle diets.

The similarity between the FBW and HCW explains why there was no effect on CL, LL, or RT. Moreover, as observed by Rotta et al. (2009), nutritional management has little effect on the variables CL, LL, and RT, which are influenced mainly by genetics. Thus, the results of the present study are indicative of homogeneity among the animals. The average result observed for conformation was 14.3 points, which is considered “very good” according to the Müller (1980) point scale. The variable LEA has been associated with the muscularity of the animal and with the yields of cuts with high commercial values; i.e., LEA is positively correlated with the edible portion of the carcass. The lack of differences for the FBWs explains the similar LEA values obtained for the supplements.

The lower total DM intake from the supplements with higher levels of castor meal may explain the reduction of the FCD, since FBW and HCW were similar, which indicates that the protein and energy consumed from the diets were directed to the accumulation of muscle and did not supply sufficient remnants for the accumulation of fat, as occurred with the lower levels of castor meal, for which the intakes of DM and TDN were greater in relation to BW.

According to Eiras et al. (2014), the meat Brazilian market requires a minimum of 3 mm of FCD for good marketing, this fat cover thickness prevents losses resulting from drying and darkening of the meat during chilling. By contrast, in addition to being undesirable, high FCD values may reduce the yield of the edible portion, and this fat needs to be trimmed off for sale, which implies waste (Kazama et al., 2008). The texture, marbling, and color of the meat averaged 3.93, 6.29, and 4.15 points, respectively, which suggests that the meat was “slightly coarse” with “light” marbling and a “red” color, according to the Müller (1980) point scale. These characteristics can be associated with meat tenderness and juiciness and the acceptance of the meat by the consumer market.

Ruminants adapt to different environments by modifying their feeding behaviors; i.e., managing their feed intake to meet their nutritional requirements, and these modifications are reflected in their productive performance (Sichonany et al., 2015). Thus, the animals that received the diets with higher fiber contents and lower energy densities increased their grazing time and the time they spent at the trough to maintain their feeding pattern. However, this feeding pattern was not sufficient to maintain a total DMI similar to that observed following the supply of the supplements with lower amounts of castor meal despite the linear increase in FQI.

Because of the energy density and higher fiber content consumed, the animals that received the supplements that contained more castor meal increased their FQI and also showed a linear increase in FQO (Table 6). The percentages of rumination and lying idle showed values greater than 50% of the total rumination time and the time spent on other activities (average 83.89% and 52.51%, respectively). Rumination activity can occur while the animal is standing or lying; however, when lying, the animal is in better welfare conditions.

Although no significant differences were noted for RUM or FR, the TRP increased due to the greater intake of fibrous material, which generated a greater need for rumination throughout the day even in short periods. According to Grandis et al. (2015), with a higher participation of roughages in the diet and a higher percentage of effective fiber, a longer time for feed intake and rumination is expected, reflecting in a shorter idle time.

Conclusions

The use of castor meal in supplements for heifers on pasture up to 1000 g/kg DM replacing soybean meal in the proportion of 0.7 kg/100 kg of their body weight reduces dry matter intake but does not change their average weight gain or feed efficiency; thus, it can be recommended as strategy to reduce production costs. Thus, the use of castor meal is a recommendable strategy to reduce production costs in a beef cattle grazing system.

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Received: 9 VIII 2017
Accepted: 6 XII 2017