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REGULAR ARTICLES

Detoxified castor seed meal replaces soybean meal in the supplement for Holstein-Zebu crossbred steers finished on tropical pasture during the rainy season

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Abstract

The objective of this study was to examine the effect of replacing soybean meal (SBM) with detoxified castor seed meal (DCM) on the intake, digestibility, feeding behavior, and performance of pasture-finished (rainy season) steers supplemented with concentrate at 0.4% of their body weight. Forty ½ Holstein + ½ Zebu steers (initial weight: 283.3 ± 36.3 kg) were allocated to four treatments in a completely randomized experimental design. Treatments consisted of diets in which DCM replaced 0, 30, 60, and 90% of SBM in the supplement dry matter (DM). The steers were finished on an *Urochloa brizantha* pasture and the experiment lasted 112 days. Replacing SBM with DCM did not influence ($P > 0.05$) the intake or apparent digestibility of DM, crude protein, or neutral detergent insoluble fiber of the animals. Grazing time increased ($P < 005$), whereas the intake and rumination efficiencies of the steers did not change ($P > 0.05$) with the substitution. The replacement of SBM with DCM in the supplement fed to the steers also did not influence ($P > 0.05$) their final weight, average daily gain, or feed conversion ($P > 0.05$). We recommend replacing up to 90% (DM basis) of SBM with DCM in the concentrate supplement of steers grazing on *Urochloa brizantha* pasture during rainy season while supplemented with concentrate at 0.4% of their body weight.

Keywords Biodiesel by-product · Feeding behavior · Post-weaning on pasture · *Ricinus communis*

Introduction

Ruminant livestock has a prominent role in the scenario of food and environmental security by ensuring the supply of high-biological-value protein for the human population through the bioconversion of forage and agricultural/agro-industrial wastes into meat, milk, and derivatives. However, in tropical areas of the world, climatic seasonality alters the availability and quality of forage for cattle herds. In this context, strategies such as concentrate supplementation (protein or protein-energy) emerge as an alternative to increase the efficiency of these animals (Brandão et al. 2016; Rocha et al. 2019).

During the dry season, the composition of supplements should optimize the utilization of the energy contained in the forage fiber through the input of rumen-degradable protein (RDP), which stimulates microbial growth and fiber fermentation in the rumen (Manoukian et al. 2021). However, during the rainy season, the composition of the supplements should prioritize the input of protein slowly degraded in the rumen or rumen-undegradable protein (RUP), balancing the levels of RDP and RUP with the energy available to cattle (Roth et al. 2019). Unfortunately, soybean meal is not indicated as the main source of protein to be used in the supplement of cattle finished on pasture during the rainy season due to its high RDP content (Carrera et al. 2012).

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Conversely, detoxified castor seed meal (DCM), with its high levels of RUP due to the detoxification process (Diniz et al. 2011), can be a strategic protein ingredient to compose supplements for cattle in the rainy season. Some studies on the use of DCM in supplements for cattle in the dry-rainy season transition (Barros et al. 2011) and in the dry season (Araújo et al. 2021; Lima et al. 2022) reported decreases in intake and nutrient digestibility, but without major effects on performance. These authors recommended replacing between 90 and 100% of SBM with DCM in the supplement of pasture-finished cattle. Nevertheless, there are no studies investigating the use of DCM in the supplement of cattle finished on tropical pastures during the rainy season.

Our hypothesis is that due to its high RUP content, DCM can replace SBM in the supplement and improve the performance of steers finished on tropical pasture during the rainy season. Therefore, the objective of this study was to examine the effect of replacing SBM with DCM in the supplement on the intake, digestibility, feeding behavior, and performance of Holstein-Zebu crossbred steers finished on a *Urochloa brizantha* pasture (rainy season) while supplemented with concentrate at 0.4% of their body weight.

Materials and methods

Experimental site and animals

The experiment was carried out in the municipality of Ribeirão do Largo—BA, Brazil (15°26′46″ S, 40°44′24″ W). According to the Köppen-Geiger classification, the climate in the region is considered tropical (Aw). The entire experiment (112 days) was conducted during the rainy season.

Forty ½ Holstein + ½ Zebu crossbred steers with average initial weight of 283.3 ± 36.3 kg and an average age of 26 months were used. Before the experimental period, the animals were identified, treated against ecto- and endoparasites (Ivermectin LA 3.5%), weighed, and allocated to four lots with ten animals each, in a completely randomized design. The steers were led to a 14-ha pasture of *Urochloa brizantha* cv. Marandu, which was divided into 12 paddocks of approximately 1.17 ha each and managed in an intermittent grazing system. Three modules of four paddocks were utilized to reduce the possible effect of biomass variation across paddocks. The animal lots were rotated across modules every 28 days and changed paddocks within the same module every seven days.

The tested treatments consisted of diets with increasing levels of detoxified castor seed meal (0 = control, 30, 60, and 90%, DM basis) replacing soybean meal in the supplement for steers. The diet was formulated to provide a weight gain of 1 kg/day, in accordance with the requirements set forth by the NRC (2016). The concentrate supplement was supplied to allow an intake of 0.4% of the animals' body weight (BW), and formulated with grain sorghum, soybean meal, detoxified castor seed meal, urea, and mineral salt (Table 1). The castor seed meal used in the experiment had been previously detoxified with calcium oxide (CaO) at a rate of 60 g per kilogram of meal (Oliveira et al. 2010). Supplement was provided daily, at 10:00 h in uncovered collective plastic troughs with double access and with a linear dimension of 70 cm per animal.

Forage evaluation

The forage was monitored every 28 days, to assess its quality at the moment of supply when the animals entered the paddock and to measure the amount of residual forage after their exit.

Forage availability was evaluated by sampling both the four occupied paddocks (exit) and the paddocks that would be used later (entry), using the double-sampling method. Before cutting at ground level, the sample's biomass availability was estimated using the scale of scores proposed by Haydock and Shaw (1975). For this evaluation, samples within a 0.25-m^2 square were cut at ground level on the first day of each period, in each paddock.

Forage samples collected in each paddock were weighed to determine forage availability. Then, a composite sample was made and frozen for later analysis of chemical composition. Another sample was collected whose components (leaf blade, stem, and dead material) were separated manually, weighed to determine their percentage, and finally frozen for later chemical composition analysis.

To evaluate the chemical composition of the consumed forage, samples were collected by the simulated-grazing technique (Johnson, 1978). To estimate the accumulation of biomass over time, the triple-pairing technique was applied on the four paddocks that remained sealed for 28 days, which functioned as exclusion cages. Dry matter accumulation in the different periods was calculated by multiplying the daily DM accumulation rate by the number of days in the period.

The daily DM accumulation rate (DAR) was determined using the equation proposed by Campbell (1966). Stocking rate (SR) was calculated by considering an animal unit (AU) as 450 kg of BW and the total number of animal units by the entire experimental area. The potentially digestible DM of the pasture was calculated as described by Paulino et al. (2006). Forage allowance (FA) calculated as follows: $FA = [(RBM + DAR)/LW_{Total}] * 100$, where FA = forage allowance (kg DM/100 kg BW/day); RBM = total residual biomass (kg DM/ha/day); DAR = daily DM accumulation rate (kg DM/ha/day); and LW_{Total} = total live weight of the animals (kg/ha).

Table 1 Percentage and chemical composition of the supplements used

	Urochloa brizantha	DCM	Replacement level (%)			
			0	30	60	90
Ground sorghum			62.2	62.1	62.0	62.0
Soybean meal			30.7	21.5	12.3	3.1
Detoxified castor seed meal (DCM)			0.0	9.3	18.6	27.9
Urea			4.0	4.0	3.9	3.9
Mineral mixture[1]			3.2	3.2	3.2	3.2
DM[2] (g/kg, as fed)	304.2	877.6	881.6	880.9	854.8	865.4
MM[3] (g/kg DM)	94.6	169.0	56.4	73.2	83.3	92.5
CP[4] (g/kg DM)	113.6	365.2	334.0	321.5	305.9	291.9
EE[5] (g/kg DM)	15.3	14.7	6.6	5.9	4.9	4.1
NDFap[6] (g/kg DM)	624.2	507.5	322.9	353.3	387.2	417.7
NFC[7] (g/kg DM)	152.4	56.4	342.1	302.9	400.3	367.3
iNDF[7] (g/kg DM)	163.5	451.1	89.0	43.1	83.3	148.0

[1]Content per kg: calcium—185 g; phosphorus—60 g; sodium—107 g; sulfur—12 g; magnesium—5,000 mg; cobalt—107 mg; copper—1,300 mg; iodine—70 mg; manganese—1,000 mg; selenium—18 mg; zinc—4,000 mg; iron—1,400 mg; fluorine—600 mg. [2]Dry matter; [3]Mineral matter; [4]Crude protein; [5]Ether extract; [6]Neutral detergent fiber corrected for ash and protein; [7]Corrected non-fiber carbohydrates; [8]Indigestible neutral detergent fiber

Chemical composition of forage, supplement, and feces

The chemical composition of feces, forage, and supplements was analyzed after these materials were dried in a forced-air oven and ground in a Wiley mill to 1-mm particles. The contents of dry matter (DM), mineral matter (MM), crude protein (CP) and ether extract (EE) were determined following the methodologies described by AOAC (1990). The neutral detergent fiber (NDF) content corrected for ash and protein was determined as recommended by Mertens (2002) and Licitra et al. (1996). The non-fiber carbohydrate (NFC) content of the samples that did not contain urea was calculated using the equation proposed by Weiss (1999): $NFC = 100 - (CP + EE + Ash + NDFap)$, where CP = crude protein content; EE = ether extract content; Ash = ash content; and NDFap = neutral detergent fiber content corrected for ash and protein. For the samples containing urea, the NFCap content was estimated as proposed by Hall (2003): $NFCap = 100 - [(CP - \%CP_{Urea} + Urea) + EE + NDFap + MM]$, where NFCap = non-fibrous carbohydrates content corrected for ash and protein; CP = crude protein content of the concentrate supplement; $\%CP_{Urea}$ = protein equivalent from urea; urea% = urea content of the concentrate supplement; EE = ether extract content; NDFap = neutral detergent fiber content corrected for ash and protein; and MM = mineral matter content. All terms are expressed as % of DM.

The total digestible nutrient (TDN) content was calculated by the methodology of Weiss (1999), using a formula involving NDFap and the NFC data: $TDN = (DCP + DNDFap + DNFCap) + (2.25 \times DEE)$, where DCP = digestible CP; DNDFap = digestible NDFap; DNFCap = digestible NFCap; and DEE = digestible EE.

Nutrient intake and apparent digestibility

All animals in the experiment participated in the digestibility trial. To estimate fecal output (FO), chromic oxide was used as an external marker, which was provided daily in a single dose of 10 g, for 11 days. This period consisted of seven days for adaptation and regulation of the marker's excretion flow followed by five days of fecal collection.

Feces were collected once a day, in the paddock where the animals were located. Immediately after spontaneous defecation, feces samples were collected from the fecal bolus directly from the soil. These were stored in a freezer at -10 ºC and subsequently processed and analyzed by atomic absorption spectrophotometry for chromium determination by method INCT–CA M-005/1, following the methodology described in Detmann et al. (2021).

To determine the individual intake of supplement, titanium dioxide (TiO_2) was used as an external marker (15 g/animal), which was mixed with the supplement immediately before supply, following the same fecal collection scheme described for chromic oxide. The titanium concentration was determined by method INCT–CA M-007/1 (Detmann et al. 2021). Individual concentrate intake was estimated by dividing the total TiO_2 excretion by its respective concentration in the concentrate.

Voluntary roughage intake was estimated using the internal marker indigestible NDF (iNDF), after ruminal incubation of 0.5-g samples of forage, concentrate, and feces, in duplicate, for 288 h. These samples had been ground to 2 mm and were incubated inside non-woven fabric ('TNT') bags (grammage 100 [100 g/m^2]) with dimensions of 5 × 5 cm, as per method INCT–CA F-009/1 (Detmann et al. 2021).

Total DM intake was estimated as follows: Total DM intake (kg/day) = [(FO × CMF) – MS] + SDMI / CMR, where FO = fecal output (kg/day), obtained using chromic oxide; CMF = concentration of the iNDF marker in the feces (kg/kg); MS = quantity of the iNDF marker in the supplement (g); SDMI = supplement DM intake (kg/day); and CMR = concentration of the iNDF marker in the roughage (kg/kg).

Feeding behavior

The behavioral variables evaluated in this study were the times steers spent grazing, ruminating, idling, and feeding at the trough. Behavioral activities were considered mutually exclusionary. Observations were performed every 5 min, over a period of 96 uninterrupted hours. At the end of each 24-h period, the animals were rotated across the paddocks to reduce the influence of differences inherent to the paddocks. Time series discretization was performed as described by Silva et al. (2006).

The number of cud chews and the time spent in ruminating each cud were determined in each animal, by observing three cycles of cuds in two periods of the day (before and after the supply of the concentrate) (Bürger et al. 2000). To obtain the number of daily cuds, the total rumination time was divided by the average time spent in ruminating each cud (described above). Dry matter intake per cud was obtained by dividing the average individual intake by the number of cuds chewed per day. Biting rate was estimated as the time taken to perform 20 bites. To calculate the bite mass, the daily intake was divided by the total number of daily bites. The results of biting and swallowing observations were recorded on six occasions throughout the day (Baggio et al. 2009)—three in the morning and three in the afternoon—and were also used to determine the number of bites per day, which is the product of biting rate and grazing time.

Dry matter and NDF intakes per meal were obtained by dividing the average individual intake of each fraction by the number of feeding bouts per day. The intake and rumination efficiencies, expressed in g DM/h and g NDF/h, were obtained by dividing the average daily intake of DM and NDF by the total time spent in feeding and/or ruminating within 24 h, respectively.

Animal performance

Animal performance (average daily gain = ADG) was determined as the difference between the final and initial body weights divided by the number of days in the experimental period. Weighing events were preceded by a 12-h fast. Feed conversion (FC) was determined as a function of intake and animal performance, as shown in the equation below: FC = (DMI/ADG), where DMI = daily dry matter intake (kg/day); and ADG = average daily gain (kg).

Statistical analysis

Data were evaluated by analysis of variance and contrasts were tested for linear and quadratic effects according to the level of replacement of SBM with DCM, at a significance level of 5%, using the System for Statistical and Genetic Analysis. The statistical model was as follows: Yijk = m + Ti + eijk, where Yijk = observed value of the variable; m = general constant; Ti = effect of diet i; and Eijk = residual.

Results

Forage allowance averaged 11.82 ± 2.98%, whereas the potentially digestible DM corresponded to 8.53 ± 2.10% of the steers' BW, on average (Table 2).

Replacing SBM in the steers' supplement with DCM did not affect ($P > 0.05$) their forage, supplement, or total DM intake in kg/day (Table 3). Likewise, when evaluated relative to the animals' BW, forage (1.87 ± 0.29%), supplement

Table 2 Evaluation of *Urochloa brizantha* (rainy season) in the finishing of steers fed a supplement containing detoxified castor seed meal replacing soybean meal

	November	December	January	February	March	Mean	SDM[1]
Forage allowance (%BW[2])	8.08	9.38	12.48	14.74	14.41	11.82	2.98
pdDM[3] (%BW)	5.87	6.99	8.83	11.00	9.97	8.53	2.10
Daily accumulation rate (kg/ha/day)	98.92	145.58	214.38	225.68	236.78	184.27	59.50
Stocking rate (AU/ha)	1.79	1.94	2.19	2.37	2.51	2.16	0.30

[1]Standard deviation of the mean. [2]Body weight. [3]Potentially digestible dry matter

Table 3 Intake and apparent digestibility of diet nutrients by steers finished on *Urochloa brizantha* pasture (rainy season) while fed a supplement containing detoxified castor seed meal replacing soybean meal

Variable	Replacement level (%)				SEM[1]	*P*-value[2]	
	0	30	60	90		L	Q
Intake (kg/day)							
Forage DM	7.11	7.47	7.37	7.46	1.134	0.5436	0.7056
Supplement DM	1.56	1.64	1.56	1.57	0.411	0.9338	0.8192
Total DM	8.67	9.11	8.93	9.03	1.140	0.5681	0.6464
Organic matter	7.94	8.32	8.12	8.25	1.037	0.6194	0.6971
Crude protein	1.23	1.19	1.16	1.14	0.154	0.1898	0.8680
NDFap[3]	4.97	5.36	5.09	5.26	0.714	0.5441	0.6308
Ether extract	0.11	0.12	0.11	0.11	0.015	1.0000	0.6503
Non-fibrous carbohydrates	1.65	1.67	1.78	1.75	0.212	0.1812	0.7095
Total digestible nutrients	4.90	5.26	4.95	4.83	0.819	0.6526	0.3666
Apparent digestibility (g/kg)							
Dry matter	576.8	594.6	575.0	542.0	48.376	0.0760	0.1034
Organic matter	603.3	620.8	600.8	573.2	45.214	0.0916	0.1084
Crude protein	602.7	613.3	595.2	576.7	46.838	0.1543	0.2500
NDFap	553.9	582.1	551.2	534.4	75.478	0.4106	0.3539
Ether extract	500.1	488.6	387.9	407.6	102.480	0.0129	0.6308
Non-fibrous carbohydrates	773.6	755.3	759.5	693.9	81.648	0.0460	0.3577

[1]Standard deviation of the mean. [2]Probability of linear and quadratic effects. [3]Neutral detergent fiber corrected for ash and protein

(0.4 ± 0.09%), and total DM (2.27 ± 0.27%) intake also did not change ($P > 0.05$). Replacing SBM with DCM did not influence ($P > 0.05$) the intakes of CP, EE, NDF, NFC, or TDN by the steers. The apparent digestibilities of DM, OM, CP, and NDF also did not change ($P > 0.05$) in response to the substitution. There was a linear decrease ($P < 0.05$), however, in the apparent digestibility of the EE and NFC.

The ingredient replacement increased ($P < 0.05$) grazing time but reduced the time spent in feeding at the trough (Table 4). The number of bites per day increased ($P < 0.05$) with the substitution. Replacing SBM in the supplement with DCM did not influence ($P > 0.05$) DM and NDFap intake or rumination efficiency.

The final weight, average daily gain, and feed conversion of the steers were also unaffected by the substitution ($P > 0.05$) (Table 5).

Discussion

Replacing SBM with DCM reduced the supplement's CP content by 12% and EE content by 33%. In contrast, the NDFap and iNDF contents of the supplement increased by 29 and 66%, respectively. Despite these, the ingredient replacement did not affect the steers' DM intake—from forage, supplement, or total—, possibly due to the modest level of supplementation adopted (0.4% BW, DM basis) and the high availability of forage (forage allowance of 11.82 ± 2.82% BW) to the animals (Almeida et al. 2022).

The amount of potentially digestible DM available (average of 4237 kg/ha) ensured the possibility of selection, allowing the animals to modulate their nutrient intake through the pasture-supplement interaction (see increase in grazing time) (Barbero et al. 2015).

Crude protein intake was similar between the groups (average of 1.17 ± 0.15 kg/day) despite the reduction of 42 g/kg in the CP content of the supplement following the replacement of SBM with DCM. It is possible that the high CP content of the forage consumed by the animals (113.6 g/kg in DM) contributed to the similar CP intakes observed (Sousa et al. 2022). The CP content estimated for the total diet was, on average, 146.12 g/kg above the minimum value proposed by Sampaio et al. (2009) to increase the ruminal degradation of the NDF from the forage consumed by steers.

Replacing SBM with DCM increased the NDFap and iNDF contents of the total diet but did not influence NDFap intake, possibly due to the particle size (3-mm sieve) of the DCM that was added to the supplement. It is likely that DCM disappeared from the rumen by passage due to its small particle size and high density (Dufreneix et al. 2018). Regarding the pasture, the animals consumed approximately 1.31 ± 0.02% of their BW in NDFap, which indicates the quality of forage available to the steers (Detmann et al. 2014a). The composition of the *Urochloa brizantha* grass used in this study included 624.2 g/kg NDFap and 152.4 g/kg NFC, a fiber content consistent with those of grasses of

Table 4 Feeding behavior of steers finished on *Urochloa brizantha* pasture (rainy season) while fed a supplement containing detoxified castor seed meal replacing soybean meal

Variable	Replacement level (%)				SEM[1]	*P*-value[2]	
	0	30	60	90		L	Q
Grazing time (min)	422.38	432.00	462.88	454.13	75.055	0.0187	0.4436
Idle time (min)	567.88	571.38	540.75	538.88	86.141	0.0555	0.8446
Rumination time (min)	415.63	411.50	407.88	423.13	54.673	0.6293	0.2652
Trough time (min)	34.75	25.40	23.95	26.67	7.587	< 0.001	< 0.001
Number of bites (n/swallow)	19.28	18.35	18.08	18.65	2.066	0.1450	0.0237
Biting time (s/bite)	25.15	25.63	24.53	23.78	3.848	0.0560	0.3143
Number of bites (n/day)	20,167.83	18,654.60	21,513.58	21,551.07	4,153.553	0.0163	0.2312
Number of bites (n/min)	48.13	43.73	47.30	47.55	7.754	0.7332	0.0558
Dry matter intake (g/bite)	81.65	82.97	75.82	83.87	28.282	0.0816	0.2395
Cud chews (n/observation)	49.92	53.33	48.93	49.55	8.833	0.3907	0.3310
Chewing time (cuds/s)	51.70	53.35	51.20	48.03	7.697	0.0159	0.0476
Cuds chewed (n/day)	489.75	465.25	492.90	526.73	60.482	0.1158	0.1381
Cud chews (n/day)	24,194.17	24,592.16	23,627.40	25,679.07	4,246.850	0.2494	0.2224
Dry matter (g/cud)	18.14	20.00	18.95	17.64	3.082	0.3591	0.5669
Intake efficiency (g DM[3]/h)	1.17	1.25	1.14	1.14	0.248	0.2694	0.3426
Intake efficiency (g NDFap[4]/h)	0.67	0.73	0.65	0.66	0.146	0.3317	0.3089
Rumination efficiency (g DM/h)	1.28	1.35	1.35	1.30	0.234	0.7135	0.1117
Rumination efficiency (g NDFap/h)	0.73	0.79	0.77	0.76	0.139	0.6187	0.1023

[1]Standard deviation of the mean. [2]Probability of linear and quadratic effects. [3]Dry matter; [4]Neutral detergent fiber corrected for ash and protein

Table 5 Performance of steers finished on *Urochloa brizantha* pasture (rainy season) while fed a supplement containing detoxified castor seed meal replacing soybean meal

	Replacement level (%)				SEM[1]	*P*-value[2]	
	0	30	60	90		L	Q
Initial body weight (kg)	280.4	288.7	283.3	280.9	-	-	-
Final body weight (kg)	391.1	404.8	389.4	398.4	42.909	0.9171	0.8635
Average daily gain (kg)	0.99	1.04	0.95	1.05	0.155	0.6722	0.5854
Feed conversion (kg)	8.88	10.16	9.53	8.60	3.384	0.7672	0.3133

[1]Standard deviation of the mean. [2]Probability of linear and quadratic effects

the genus *Urochloa* in the vegetative stage during the rainy season (Delevatti et al. 2019).

Animals received an average TDN intake of 4.92 ± 0.82 kg/day, and this variable was not influenced by the inclusion of DCM in their supplement, possibly due to the similarity of digestible fractions in the total diet (Koscheck et al. 2013). The TDN content of the total diet was approximately 550 g/kg DM. This value is very close to the observed digestibility of DM (575.90 ± 48.38 g/kg) and OM (602.05 ± 45.21 g/kg). The TDN levels and the DM and OM digestibility values therefore demonstrate the success of low supplementation (0.4% BW), including at the maximum level of DCM, in increasing rumen microbial growth and the dynamics of fermentation in the utilization of the nutrients from the forage (Detmann et al. 2014b). This is evidenced by NDF digestibility (552.75 ± 75.48 g/kg), which was very close to DM digestibility.

The observed decrease in EE digestibility was possibly due to the greater presence of cutin (Carrera et al. 2012) and residual ricinoleic acid, both in DCM. The reduction in NFC digestibility may be due to the predominance of structural carbohydrate-degrading microbiota in the rumen of steers that were fed diets with a higher level of DCM (higher NDFap content), which reduced the trophic niche of non-structural carbohydrate-degrading bacteria by competition and therefore reduced NFC digestibility (Wei et al. 2021).

Grazing time increased by approximately 30 min/day with the replacement of SBM with DCM, probably due to the longer time devoted to forage selection by the steers that were supplemented with higher levels of DCM (Tedeschi et al. 2019). It is possible that the steers selected the more digestible portions of the forage, given the availability of pasture (8.53 ± 2.10% BW of potentially digestible DM), which increased the consumption of leaves and apexes of the grass to the detriment of the stem and senescent portions (Mganga et al. 2021). This can be evidenced by the increase in grazing time (active search and selection for more tender portions) and in the number of bites per day (greater exploration of the canopy and more selective grazing) and the shorter chewing time per cud (chewed cud with more tender portions) (Boval and Sauvant 2021) observed in the steers that consumed higher levels of DCM.

The increase in grazing time, provided by the inclusion of DCM, was not sufficient to influence the steers' DM or NDF intake efficiency. Rumination efficiency (DM and NDFap) was not influenced, possibly due to similarities in rumination time and DM intake between the steers that received supplement with DCM replacing SBM. Lima et al. (2022) also did not observe an influence of replacing SBM with DCM on the intake and rumination efficiency of steers finished on pasture in the dry season.

The similarity observed in TDN intake and digestible CP intake (0.70 kg/day) among diet groups explains the equal final weight and average daily gain of the steers that received supplement with SBM (BR-CORTE 2016). This shows that, on well-managed *Urochloa brizantha* pastures, during the rainy season, the CP content of the supplement offered to steers may be lower than that recommended by the NRC (2016)—from 334 to 292 g/kg, as observed here—, without compromising animal performance. In addition, from an operational point of view, the steers obtained an average gain of 46.87 kg per animal in 112 days, during the rainy season, i.e. 133.75 kg/ha, considering a stocking rate of 2.14 AU (equivalent to a 450 kg animal) per hectare. This performance is twice as high as the Brazilian average weight gain, which is 50–60 kg/ha annually (IBGE 2022). This result demonstrates the benefit of supplementation—even at a low level (0.4% BW)—in raising productivity as well as the potential of DCM as a substitute for SBM in the supplementation of grazing steers.

Conclusion

Partial replacement of soybean meal with detoxified castor seed meal in the supplement did not affect the intake, digestibility, or performance of the pasture-finished steers. Therefore, we recommend replacing up to 90% (dry-matter basis) of soybean meal with detoxified castor seed meal in the supplement of steers grazing on *Urochloa brizantha* pastures while supplemented with concentrate at 0.4% of their body weight during the rainy season. Therefore, it becomes an excellent alternative to reduce production costs, having the availability and quality of the product as a limiting factor, since detoxified castor seed meal is an industrial by-product.

Authors' contributions Silvia Layse Mendes Machado, Fabiano Ferreira da Silva, Gleidson Giordano Pinto de Carvalho, Laize Vieira Santos, João Wilian Dias Silva and Tarcísio Ribeiro Paixão conceptualized the study design, collected data, and conducted the experiment. Vanessa Alexandre Vieira, Ana Paula Gomes da Silva and Marceliana da Conceição Santos performed data analysis. Dorgival Morais de Lima Júniorr wrote the first draft of the paper. Robério Rodrigues Silva reviewed and commented on the first draft. All authors reviewed and approved the final manuscript.

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Data availability Not applicable.

Code availability Not applicable.

Declarations

Ethics approval All experimental procedures complied with the Ethics Committee on Animal Use (license 084/2015, Ethics Committee on Animal Use/Southwestern Bahia State University, UESB, Bahia, Brazil).

Consent to participate Not applicable.

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Conflict of interest The authors declare that there are no competing interests.

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