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REGULAR ARTICLES

Finishing of grazing crossbred steers supplemented with detoxified castor bean meal (*Ricinus communis* L.) in the rainy-dry transition period

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Abstract

This study evaluated levels of replacement of soybean meal by castor bean meal in the finishing crossbred steers on *Brachiaria brizantha* cv. Marandu pasture during the rainy-dry transition period. Forty Holstein-Zebu crossbred steers with an average initial weight of 395.93 ± 10 kg were randomly allocated to four treatment groups that were supplemented with concentrate levels of replacing (0, 290, 613, and 903 g/kg DM of the supplement; at 0.4% body weight [BW]). The experimental period was 120 days. A completely randomized experimental design was adopted; with regression analysis using the computational software package (SAS 9.2, USA). Intake and digestibility of dry matter (DM) and nutrients and animal performance were evaluated. The replacement levels did not influence ($P > 0.05$) the intakes of DM (kg/day), organic matter (OM, kg/day), neutral detergent fiber (NDF, kg/day and %BW), non-fibrous carbohydrates (NFC, kg/day), or total digestible nutrients (kg/day). However, the intake of crude protein (CP) and ether extract (EE, kg/day) decreased as the replacement levels were increased ($P < 0.05$). The digestibility of DM, OM, NDF, and EE did not change, whereas CP digestibility decreased linearly and NFC digestibility increased linearly ($P < 0.05$). The replacement levels did not affect ($P > 0.05$) final body weight, average daily gain, feed conversion, and carcass yield. Castor bean meal can replace up to 903 g/kg DM of soybean meal in the composition of the supplement without compromising the performance of steers on Marandu pasture during the rainy-dry transition period.

Keywords Beef cattle · Co-product · Pasture supplementation · Animal performance

Introduction

Pasture based beef production should be considered a complex and dynamic system. Its success is dependent on the proper management of three types of resource: basal nutritional, supplemental nutritional, and genetic (Detmann et al., 2014a, b). According to (ABIEC 2023), Brazil increased its occupancy rate by 2022. Herd growth by about 3.3%, estimated at 202 million heads, of the total animals slaughtered, 18.2% were ended in confinement. Most of the Brazilian cattle (81.8%) are raised in extensive system, to pasture, and the reduction of pasture area by 5.7% to approximately 154 million hectares, increased the rate of Brazilian occupation for 1.32 head per hectare. More animals, in smaller area, increasing the productivity. Therefore, pastures play a fundamental role in Brazilian livestock, ensuring low costs in meat

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production. For this reason, alternative solutions must be considered to meet grazing needs in view of quantitative and qualitative variables in forage resources throughout the year.

In an effort to increase efficiency and the weight gains of cattle on pasture, many supplementation strategies have been developed as well as agro-industrial by-products, e.g., castor bean meal (CBM). The aim is to reduce supplement costs, as they replace costlier ingredients such as soybean (Matos et al., 2018). According with Araújo et al. (2021), castor bean represents a good alternative in biodiesel production because it does not compete with other crops of importance in human nutrition. Castor bean is a by-product with potential for use in ruminant diets after detoxification (Antunes et al., 2019). In addition, castor growing in Brazil is a promising activity. According to Brazilian law no. 11,907/2005, 10% of biodiesel must be included in the energy matrix of the country (Abdalla et al., 2008).

The castor bean meal is generated from mechanical pressing, a step during which around 50% of the oil is removed, followed by the extraction of soluble (hexane, heptane, or petroleum ether) (Faria Filho et al., 2016). The extraction process generates wastes such as glycerin, cake, meal, and husks (Da Silva Fonseca and Soto-Blanco, 2014). Castor bean meal is an interesting alternative for ruminant feeding due to its chemical properties, which reportedly include, on average, 88.35% dry matter, 32.28% crude protein, 17.54% mineral matter, 38.08% neutral detergent fiber, 34.44% acid detergent fiber, 2.31% ether extract, and 19.50% lignin (Diniz et al., 2011; Menezes et al., 2015; Oliveira et al., 2017; Araújo et al., 2021, Ribeiro Lima et al., 2022).

However, caution is recommended when using CBM in animal diets, given toxic substances and/or anti-nutritional factors that may be present, particularly ricin, ricinine, and the allergenic fraction (CB-1A) (Carrera et al., 2012). The ricin is classified as a lectin, a protein that has a specific receptor site for a sugar or an oligosaccharide unit; it belongs to the family of lectins A-B, composed of two subunits, one with enzymatic activity and the other with a binding site specific to the sugar galactose, exerting its mechanism of toxicity through the inactivation of ribosomes leading to reduced protein synthesis in the body impairing the metabolism of the animals that consume it.

According with Sousa et al. (2017), the seeds accumulate significant amounts of ricin 40 days after pollination, ranging from 1.6 mg to 32 mg of ricin per gram of mature seed. One A-chain molecule of ricin is able to irreversibly inactivate one thousand ribosomes per minute, impairing protein synthesis and causing cell death. The B-chain binds specifically to cell surface glycoproteins or glycolipids and facilitates the movement of the A-chain into animal cells. For this reason, CBM must undergo a detoxification process to avoid possible damage to the rumen of the animal (Carrera et al., 2012). At the moment, there is no permissible level of ricin indicated, but it is well known that after detoxification treatments the toxin disappears and with it the toxic effects. The most common detoxification procedure involves the use of calcium oxide, at the rate of 60 g/kg of CBM (Oliveira et al., 2010a, b), which procedure eliminated the toxic effect of ricin.

Some studies describe CBM as being palatable to animals, which is a promising characteristic for the consumption of the total diet when supplementing grazing cattle. Nonetheless, Barros et al. (2011) evaluated the replacement of soybean meal (SBM) with CBM at 0, 330, 670, and 1000 g/kg, in the diet of grazing heifers during the dry-rainy transition period and found a reduction in dry matter intake (DMI) as the replacement levels were increased (5.96 vs. 6.37 kg/day with and without CBM in the diet). Araújo et al. (2021) reported similar findings in a study evaluated levels of replacement SBM by CBM (0, 153, 308, and 434 g/kg) for finished crossbred steers, with a reduction in DM intake at the concentration of 0.5% of the animals' body weight. However, in both experiments, the decrease in DM intake did not affect the digestibility and animal performance. Ribeiro Lima et al. (2022), evaluating grazing crossbreed steers supplemented with increasing levels of CBM (0, 90, 190 and 280 g/kg DM) replacing soybean meal, reported no decrease in the DMI, this study concluded that CBM can be included at up to 280 g/kg DM replacing soybean meal without having adverse effects on production performance or nutritional parameter.

Therefore, in this study, we hypothesized that the addition of detoxified castor bean meal as replacement of soybean meal does not negatively affect the productive performance of steers supplemented in grazing in the rainy-dry transition period. From the nutritional and economic point of view, this is a positive factor, since castor bean meal is a co-product of lower cost than foods traditionally used in ruminant diets, such as corn and soybean. In addition, the use of co-products with high nutritional content, such as castor bean bran, decreases dependence on other foods that compete with the use in human food and non-ruminant animals. In view of the foregoing and the need for further research that demonstrates the efficiency of using CBM in pasture-based cattle production, the aim of the present is to investigate different levels of replacement of SBM with detoxified CBM in the finishing of crossbred steers on *Brachiaria brizantha* cv. Marandu pasture during the rainy-dry transition period.

Materials and methods

Animals, management, and diets

All experimental procedures complied with the rules set forth by the Ethics Committee on Animal Use at the

Universidade Estadual do Sudoeste da Bahia (CEUA-UESB) (approval no. 51/2015; December 02, 2013). The experiment was carried out on the "Princesa do Mateiro" farm, in Ribeirão do Largo—BA, Brazil (15°27′32" S, 40°44′20" W, 800 m above sea level). The region is characterized by a humid tropical climate (Köppen, 1936), with average annual precipitation of 800 mm and average annual temperature of 27 °C. Was used an area of 14 ha, which was divided into 12 paddocks of approximately 1.17 ha each, covered with *Brachiaria brizantha* cv. Marandu (previously fertilized with urea at 100 kg/ha). The animals were managed in an intermittent grazing system, in three modules of four paddocks.

Forty crossbred (Holstein × Zebu) steers with an average initial weight of 395.93 ± 10 kg were divided into groups of 10 animals and each group remained in a paddock for seven days (four paddocks occupied). The animals were weighed and allocated in a completely randomized design, and were identified by plastic earrings with individual numbers. The supplement was given so as to provide an intake of 0.4% BW. All steers were fed in a finishing system for 120 days, during the rainy-dry transition period, after a period of 14 days of adaptation to the diet. The supplement was provided daily, at 10:00 a.m., in uncovered collective plastic troughs with double access and 70 linear centimeters per animal.

The supplement contained ground corn, SBM, detoxified CBM, urea, and mineral salt in the proportions shown in Table 1. The tested levels of detoxified CBM replacing SBM in the concentrate were CB00-without castor bean meal; CB30-290 g/kg of castor bean meal; CB60-613 g/kg of castor bean meal and CB90-903 g/kg of castor bean meal. The diet was formulated for a daily weight gain of 1 kg according to the requirements recommended by the NRC- Nutrient Requirements of Beef Cattle (2016).

Table 1 Proportion of ingredients in the composition of the supplement containing detoxified castor bean meal as a replacement for soybean meal for steers grazing on *Brachiaria brizantha* cv. Marandu pasture

Ingredients (g/kg DM basis)	Replacement level CBM by SBM (g/kg)			
	CB00	CB30	CB60	CB90
Ground corn	620.00	620.00	620.00	620.00
Soybean meal	310.00	220.00	120.00	30.00
Castor bean	0.00	90.00	190.00	280.0
Mineral salt[a]	30.00	30.00	30.00	30.00
Urea	40.00	40.00	40.00	40.00
Total	1000	1000	1000	1000

CBM castor bean meal; *SBM* soybean meal; *CB00*, without castor bean meal; *CB30*, 290 g/kg of castor bean meal; *CC60*, 613 g/kg of castor bean meal; *CC90*, 903 g/kg of castor bean meal. [a] Provides per kilogram of product: calcium—185 g, phosphorus—60 g, sodium—107 g, sulfur 12 g, magnesium—5000 mg, cobalt—107 mg, copper—1300 mg, iodine—70 mg, manganese—1000 mg, selenium—18 mg, zinc—4000 mg, iron—1400 mg, fluorine-600 mg.

Experimental procedure and sampling

The castor bean meal used in this experiment was previously detoxified before being incorporated into treatments.

using calcium oxide (CaO) at a rate of 60 g for each kilogram of meal based on natural matter following the method proposed by Oliveira et al. (2010a, b). The CaO was previously diluted with a ratio of 1:10 (1 kg CaO/10 L of water).

The forage was sampled every 28 days to evaluate the quality of forage supplied at the entrance of the animals into the paddock and the amount of residual forage after the animals left, in accordance with the double-sampling method (Wilm et al., 1994). The biomass availability of the sample was estimated according to a score scale proposed by Haydock & Shaw (1975). For this assessment, on the first day of each period, in each paddock, samples were cut at ground level using a 0.25m^2 square.

Samples collected in each paddock were weighed on a portable digital scale and then a composite sample was formed. Subsequently, these were packed in labeled plastic bags and properly frozen in a freezer at -10 °C. Afterwards, samples were taken using the grazing-simulation technique proposed by Johnson (1978), which consists of cutting the plants manually, or with a cleaver, to simulate the act of grazing by animals, observing the height of the grazed stratum and the morphological components prehended.

The daily DM accumulation rate (DAR) was estimated using the equation proposed by Cambell (1966):

$$DAR = (Gi - Fi - 1)/n,$$

where Gi = initial dry matter in the paddock; Fi – 1 = initial average dry matter in the empty paddocks at instant 1; and n = days in period.

Stocking rate (SR) was calculated considering one animal unit (AU) as 450 kg BW, using the following formula:

$$SR_{(Animal/ha)} = (AUt)/area,$$

where AUt = total animal unit.

The potentially digestible dry matter (pdDM) of the pasture was estimated as described by Paulino et al. (2006):

$$pdDM(\%) = 0.98(100 - \%NDF) + (\%NDF - \%iNDF),$$

where 0.98 = true digestibility coefficient of cell content; NDF = neutral detergent fiber; and iNDF = indigestible NDF.

The available potentially digestible DM (pdDM$_A$) was calculated using the equation described by Detmann et al. (2012):

$$pdDM_A = TDM_A * \%pdDM,$$

where TDM_A = total available DM, in kg/ha.

Forage allowance (FA) was calculated by the following formula:

$$FA = \{(RBM + DAR)/totalBW\} * 100,$$

where FA = forage allowance; RBM = total residual biomass, in kg DM/ha/day; and DAR = daily accumulation rate, in kg DM/ha/day; BW = body weight of animals, in kg/ha.

Chemical analysis of feed, leftovers, and feces

The chemical composition of Forage, feces, and ingredient samples (Tables 2 and 3) was milling though a 1-mm screen in accordance with the analytical procedures of Association of Official Analytical Chemists method ID 934.01 (AOAC 2005). Ash content was measured by combustion at 550 °C for 16 h according to method ID 942.05 (AOAC 2005). Organic matter was calculated by method ID 967.05(AOAC 2005). Nitrogen concentration was determined by the Kjeldahl method ID 988.05 (AOAC 2005). Following the determination of nitrogen concentration, crude protein was calculated by multiplying the nitrogen content by a factor of 6.25. Ether extract content was determined by method ID 920.39 (AOAC 2005).

The neutral detergent fiber content was measured according to the recommendations of Mertens (2002) using α-amylase. Neutral detergent fiber corrected for ash and crude protein following the recommendations of Mertens (2002) and Licitra et al. (1996), respectively. Indigestible neutral detergent fiber was determined after incubation in rumen-cannulated steers using F57 filter bags for 288 h (Ankom Technology, NY, USA) according to Casali et al. (2008).

Table 3 Chemical composition of the total diet used in the finishing phase of steers receiving supplement containing detoxified castor bean meal as a replacement for soybean meal, while grazing on *Brachiaria brizantha* cv. Marandu pasture

Nutritional composition (g/kg DM basis)	Replacement level CBM by SBM (g/kg)			
	CB00	CB30	CB60	CB90
Dry matter	478.70	495.10	480.10	483.10
Organic matter	914.70	911.60	908.30	907.40
Mineral matter	85.30	87.30	90.70	91.50
Crude protein	145.90	133.10	129.90	130.90
Ether extract	14.60	14.50	13.80	13.80
NDFap	605.80	601.70	608.30	612.60
Non- fibrous carbohydrates	144.80	160.50	154.30	147.90
Total Carbohydrates	750.40	762.00	762.50	760.40
Indigestible Neutral Detergent Fiber	186.10	189.30	201.30	213.60
Total Digestible Nutrients	498.30	494.60	490.10	486.00

CBM castor bean meal; *SBM* soybean meal; *CB00* without castor bean meal; *CB30,* 290 g/kg of castor bean meal; *CC60,* 613 g/kg of castor bean meal; *CC90*, 903 g/kg of castor bean meal; *NDFap* neutral detergent fiber corrected for ash and crude protein.

Non-fibrous carbohydrates (NFC) in the samples were determined using the formula described by Detmann et al. (2012):

$$NFC = 100 - (CP\% + EE\% + MM\% + NDFap),$$

where CP = crude protein; EE = ether extract; MM = mineral matter; and NDF = neutral detergent fiber.

Total digestible nutrients (TDN) were calculated as proposed by the NRC-National Research Council (2000):

Table 2 Chemical composition of the forage and the supplement containing detoxified castor bean meal as a replacement for soybean meal for steers grazing on *Brachiaria brizantha* cv. Marandu pasture

Nutritional composition (g/kg DM basis)				Replacement level CBM by SBM (g/kg)			
	SG	SBM	CBM	CB00	CB30	CB60	CB90
Dry Matter	278.90	886.40	877.60	885.40	878.50	871.00	864.20
Organic Matter	906.80	933.90	831.00	898.00	890.70	882.60	875.20
Mineral Matter	93.20	64.80	169.00	24.90	19.90	14.20	9.100
Crude Protein	99.00	489.90	365.20	190.40	187.90	185.00	182.40
Ether Extract	19.60	19.40	14.70	98.60	90.40	81.30	73.00
NDFap	684.30	131.80	507.50	141.50	174.30	210.70	243.50
NFCap	224.10	314.00	56.40	590.40	584.80	578.50	572.80
iNDF	328.50	185.00	451.10	34.70	58.80	85.70	109.80
Total Carbohydrates	104.00	428.00	391.70	662.40	657.70	652.50	647.80

SG simulated grazing; *CBM* castor bean meal; *SBM* soybean meal; *CB00*, without castor bean meal; *CB30*, 290 g/kg of castor bean meal; *CC60*, 613 g/kg of castor bean meal; *CC90*, 903 g/kg of castor bean meal; *NDFap* neutral detergent fiber corrected for ash and protein; *NFCap* non-fibrous carbohydrates corrected for ash and protein; *iNDF* indigestible neutral detergent fiber.

$$TDN = DCP + (DEE \times 2.25) + DNDF + DNFC,$$

where DCP = digestible crude protein; DEE = digestible ether extract; DNDF = digestible neutral detergent fiber; and DNFC = digestible non-fibrous carbohydrates.

Evaluation of intake and digestibility

Digestibility was measured between the 36th to 48th days of experiment. All animals were subjected to a digestibility trial of 12 days. Fecal output was estimated using chromic oxide (CrO_3) as a marker, following Smith & Reid (1955). The marker was packed in a paper cartridge that was provided, daily, orally, in a single dose (10 g/animal/day), between 06:30 a.m. and 08:00 a.m. After seven days of adaptation, five days were used for feces collection, were collected on the 8th (4:00 p.m.), 9th (2:00 p.m.), 10th (12:00), 11th (10:00 a.m.), and 12th (08:00 a.m.) days according at the methodology proposed by Saliba et al. (2000).

Feces were collected once per day, in the paddock where the animals grazed. Soon after spontaneous defecation, samples of feces were collected from the ground with care so as to avoid contamination by foreign bodies and identified. The feces were then frozen at -10 ºC and later processed and analyzed by atomic absorption spectrophotometry to measure the chromium content according to method INCT–CA M005/1 (Detmann et al., 2012).

To determine individual supplement intake, titanium dioxide (15 g/animal) was mixed with the supplement immediately before its supply, following the same fecal collection scheme described for chromic oxide. The titanium concentration was determined according to the method INCT–CA M-007/1 described by Detmann et al. (2012). Readings were taken with an absorption spectrophotometer at the Laboratory of Physiology of the Department of Basic and Instrumental Studies at the Universidade Estadual do Sudoeste da Bahia (UESB). The individual intake of concentrate 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). The marker was obtained after rumen incubation, in duplicate, of 0.5 g samples of forage, concentrate, and feces previously ground to 2 mm, inside non-woven fabric bags ("TNT", grammage of 100 g m^{-2}, 5 × 5 cm), for 288 h, following method INCT-CA F-009/1 described by Detmann et al. (2012).

Total DM intake (kg/day) was estimated as follows:

$$Total\ DM\ intake\ (kg/day) = [(FO \times MFe) - MS] + SDMI/MFo,$$

where FO = fecal output (kg/day), obtained using chromic oxide, MFe = concentration of the iNDF marker in the feces (kg/kg); MS = concentration of the iNDF marker in the supplement (kg/kg); SDMI = supplement dry matter intake (kg); and MFo = concentration of the iNDF marker in the forage (kg/kg).

Animal performance

Aims to evaluate the performance of the animals in response to the diets, they were weighed at the beginning and at the end of the experiment. Additionally, the steers were weighed every 28 days to determine the average daily gain (ADG) and adjust the provision of supplement. Weighing events were preceded by a 12 h fasting period. Animal performance (ADG) was determined as the difference between final body weight (FBW) and initial body weight (IBW) divided by the experimental period in days. Feed conversion (FC) was calculated as a function of feed intake and animal performance, according to the equation below:

$$FC = (DMI/ADG),$$

where DMI = daily dry matter intake, in kg/day; and ADG = average daily gain, in kg/day.

Aiming to obtain the carcass yield, the animal was weighted for to obtain the slaughter body weight (SBW) before that animals were fasted of solids of 16 h, and slaughtered following the processes and/or normal fluxes of the slaughterhouse and of the established rules by the normative instruction n° 3, January 17, 2000; from the Ministério da Agricultura, Pecuária e Abastecimento, Brazil. At the end of the line of slaughter, the carcass was divided in two parts and weighted to obtain the hot carcass weight (HCW), Upon the carcass were identified and chilled for 24 h at 0 °C. With this weight was calculated the hot carcass yield (HCY) using the following equation:

$$HCY = (HCW/SBW)x100$$

where HCY = hot carcass yield, in kg; HCW = hot carcass weight, in kg; and SBW = slaughter body weight, in kg.

Statistical analysis

Data were evaluated by ANOVA and regression, using SAS 9.2 computational software package (SAS institute, Cary, North Carolina, USA). The mathematical model used was: $Yijk = m + Ti + eijk$; where $Yijk$ = observed value of the variable; m = general constant; Ti = effect of diet i; and $eijk$ = error associated with each observation. Statistical models were chosen according to the significance of the coefficients of regression, using the F test at the 5% probability level, and of determination (R^2), according to the biological phenomenon studied.

Results

Total available dry matter (TDM_A), available potentially digestible dry matter ($pdDM_A$), forage mass (FM), leaf dry matter (LDM), stem dry matter (SDM), and leaf:stem ratio (L:S) averaged 6277.80, 4927.10, 3832.80, 1814.00, and 2000.60 kg/ha; and 0.91, respectively (Fig. 1). Stocking rate (SR) was 2.86 animal unites per hectare (AU/ha), with a forage allowance (FA) of 14.31% BW during the experimental period. The average precipitation and temperature recorded were 44.3 mm and 22.89 ℃, respectively (Figs. 2 and 3).

On the other hand, there was a correlation between DM availability and the temperatures, with forage production being proportional to the temperatures recorded during the experimental period, the value represented 643 kg DM per temperature unit in °C (Fig. 3).

The replacement of SBM with detoxified CBM in the concentrate, provided during the finishing phase of the crossbred steers, did not influence ($P > 0.05$) the intakes of DM, OM, forage DM, supplement DM, NDFap, NFC, or TDN expressed in kg/day or supplement DM and NDFap expressed in %BW. The respective mean values of these variables were 10.41, 9.50, 8.56, 1.85, 5.83, 1.98, and 5.13 kg/day; and 0.39 and 1.25% BW (Table 4). However, the intakes of CP and EE (kg/day) decreased as the CBM levels in the treatments were increased.

The digestibility coefficients of DM, OM, NDFap, and EE did not differ ($P > 0.05$) in response to the replacement of SBM with detoxified CBM, averaging 49.51, 53.45, 50.49, 51.01, and 48.34%, respectively. In contrast, CP digestibility decreased linearly, whereas NFCap digestibility increased linearly ($P < 0.05$) (Table 5).

In terms of animal performance, the replacement of SBM with CBM did not affect ($P > 0.05$) the final body weight (FBW), average daily gain (ADG), feed conversion (FC), and carcass yield (CY) of the steers, whose mean values found

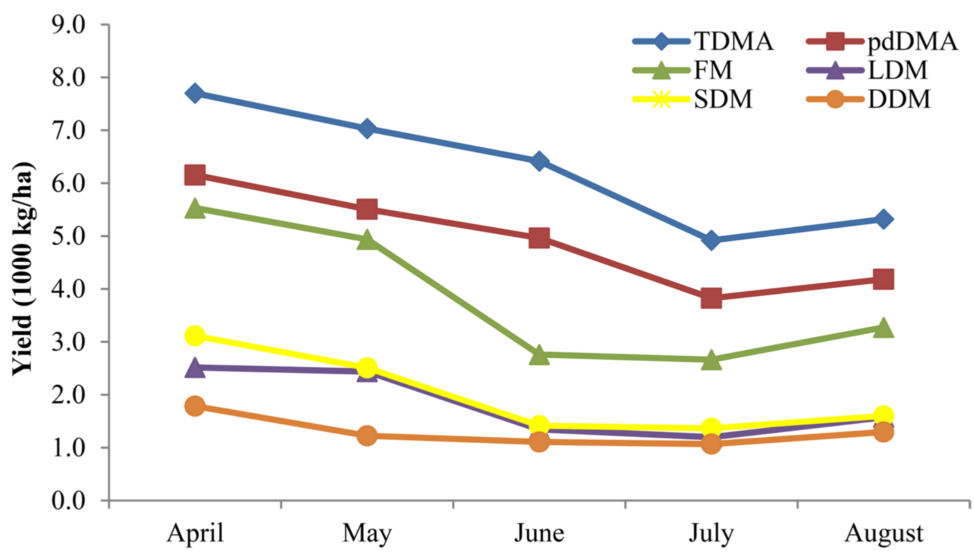

Fig. 1 Characteristics of the forage (*Brachiaria brizantha* cv. Marandu) during the experimental period. TDM_A = total available dry matter (kg/ha); FM = forage mass ((kg/ha); $pdDM_A$ = available potentially digestible dry matter (kg/ha); LDM = leaf dry matter (kg/ha); SDM = stem dry matter (kg/ha); and DDM = dead material (kg/ha)

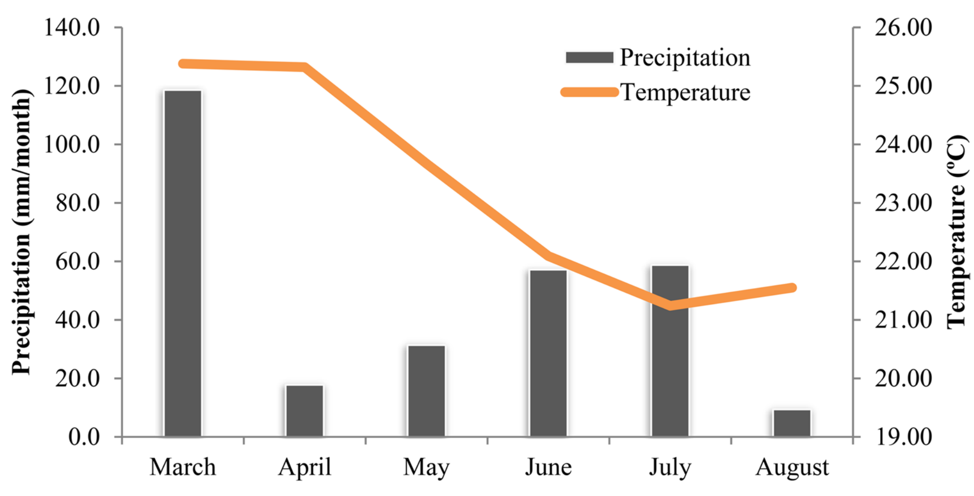

Fig. 2 Average monthly precipitation and temperatures during the experimental period

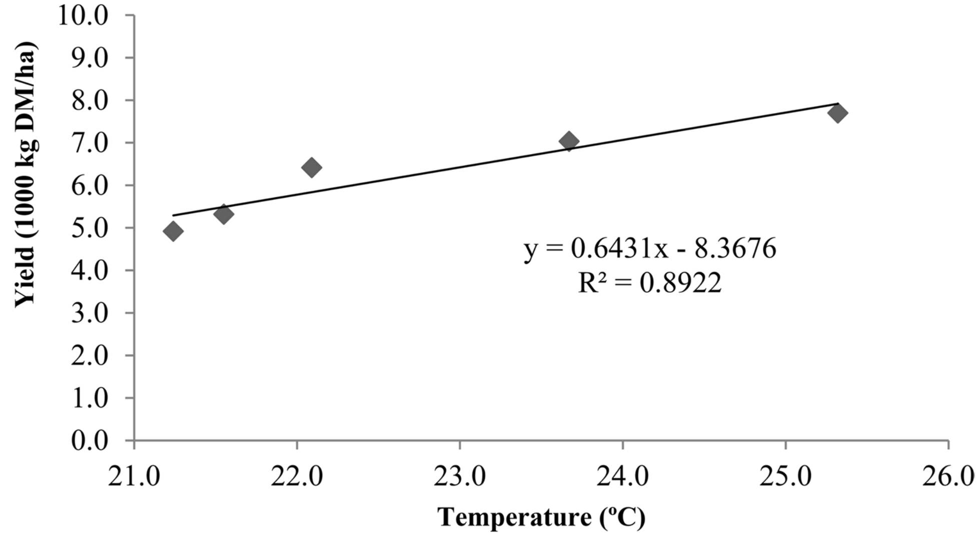

Fig. 3 Correlation between total available dry matter (TDM_A) and temperature in the experimental period (monthly temperatures)

Table 4 Nutrient intake by finishing steers receiving a supplement containing detoxified castor bean meal (CBM) a replacement for soybean meal (SBM), while grazing on *Brachiaria brizantha* cv. Marandu pasture during 120 days

Intake	Replacement level CBM by SBM (g/kg)					CV	P-value	
	CB00	CB30	CB60	CB90	RE		L	Q
TDM (kg/day)	10.26	10.79	10.28	10.29	Ŷ = 10.41	7.55	0.72679	0.30424
DM (%BW)	2.24	2.22	2.26	2.23	Ŷ = 2.24	11.39	0.96458	0.96458
OM (kg/day)	9.40	9.87	9.37	9.37	Ŷ = 9.50	9.64	0.74779	0.30453
DM_{for} (kg/day)	8.41	8.84	8.45	8.53	Ŷ = 8.56	9.29	0.97495	0.23107
DM_{sup} (kg/day)	1.85	1.95	1.83	1.77	Ŷ = 1.85	21.68	0.54254	0.51135
DM_{sup} (%BW)	0.40	0.40	0.40	0.38	Ŷ = 0.39	21.54	0.59290	0.65981
CP (kg/day)	1.53	1.46	1.37	1.38	Ŷ = 1	9.32	0.00790*	0.36776
NDFap (kg/day)	5.74	5.99	5.76	5.83	Ŷ = 5.83	8.26	0.93379	0.57334
NDFap (%BW)	1.25	1.23	1.27	1.27	Ŷ = 1.25	12.20	0.74548	0.81591
EE (kg/day)	0.14	0.14	0.13	0.12	Ŷ = 2	8.09	0.00138*	0.26229
NFCap (kg/day)	1.88	2.15	1.99	1.92	Ŷ = 1.98	15.50	0.70754	0.20906
TDN (kg/day)	5.11	5.35	5.04	5.03	Ŷ = 5.13	16.37	0.52502	0.81427

TDM total dry matter; *DM* dry matter; *BW* body weight; *OM* organic matter; DM_{for} forage dry matter; DM_{sup} supplement dry matter; *CP* crude protein; *NDFap* neutral detergent fiber corrected for ash and protein; *EE* ether extract; *NFCap* non-fibrous carbohydrates corrected for ash and protein; *TDN* total digestible nutrients; *CBM* castor bean meal; *SBM* soybean meal; *CB00* without castor bean meal; *CB30,* 290 g/kg of castor bean meal; *CC60,* 613 g/kg of castor bean meal; *CC90*, 903 g/kg of castor bean meal; *RE* regression equations: [1]Ŷ = 1.516—0.0018x (R^2 = 0.87). [2]Ŷ = 0.143—0.0002x (R^2 = 0.87); *Significance.

were 478.85 kg, 0.73 kg/day, 14.40, and 50.41%, respectively (Table 6).

Discussion

Forage evaluation

Peak production of TDM_A, $pdDM_A$, FM, and LDM and the highest leaf:stem ratio (L:S) occurred between the months of April and May, due to the rainfall in the period and nitrogen fertilizer application carried before the experiment. After this period, these variables declined linearly in July, increasing thereafter (Fig. 1).

The average TDM_A was 6.277,80 kg/ha, which is a very good result, as it is above the 5.994,00 kg DM/ha considered the minimum amount of available pasture that does not prevent the animal from achieving its maximum forage intake potential under stocking rate of 7.11 animal unit (AU) during the rainy season period found by Barbero et al. (2015). In this condition, the animal is able to select the material with the best nutritional quality-in this case, green leaves and stems.

On the other hand, considering 6277,80 kg/ha as value TDM_A and the nitrogen fertilizer application (100 kg/ha,

Table 5 Digestibility of nutrients from the diet of steers receiving a supplement containing detoxified castor bean meal a replacement for soybean meal, while grazing on *Brachiaria brizantha* cv. Marandu pasture during 120 days

Digestibility (%)	Replacement level CBM by SBM (g/kg)					CV	P-value	
	CB00	CB30	CB60	CB90	RE		L	Q
Dry matter	49.60	50.39	48.48	49.58	Ŷ = 49.51	15.00	0.85474	0.94992
Organic matter	54.27	53.82	52.39	53.30	Ŷ = 53.45	13.10	0.66061	0.75969
Crude protein	64.79	62.59	60.88	58.15	Ŷ = 1	9.80	0.01548*	0.89113
NDFap	53.24	49.09	49.64	50.00	Ŷ = 50.49	16.20	0.43328	0.38848
Ether extract	53.69	54.89	49.73	45.74	Ŷ = 51.01	22.40	0.08128	0.47761
NFCap	47.55	60.22	60.12	60.07	Ŷ = 2	21.26	0.03526	0.10558
Total digestible nutrients	49.89	49.454	45.407	48.6	Ŷ = 48.34	19.94	0.56518	0.55557

NDFap neutral detergent fiber corrected for ash and protein, *NFCap* non-fibrous carbohydrates corrected for ash and protein; *CB00* without castor bean meal; *CB30,* 290 g/kg of castor bean meal; *CC60,* 613 g/kg of castor bean meal; *CC90*, 903 g/kg of castor bean meal; *RE* regression equations: [1]$\hat{Y} = 64.847—0.0721x$ ($R^2 = 0.99$);[2]$\hat{Y} = 51.371 + 0.1249x$ ($R^2 = 0.59$);[*]Significance.

Table 6 Performance of steers receiving a supplement containing detoxified castor bean meal as a replacement for soybean meal, while grazing on *Brachiaria brizantha* cv. Marandu pasture during 120 days

Variable	Replacement level CBM by SBM (g/kg)					CV	P-value	
	CB00	CB30	CB60	CB90	RE		L	Q
IBW (kg)	391.10	404.80	389.40	398.40	Ŷ = 395.93	-	-	-
FBW (kg)	473.70	510.00	479.70	488.00	Ŷ = 487.85	8.813	0.83689	0.31002
ADG (kg/day)	0.690	0.790	0.700	0.740	Ŷ = 0.73	10.764	0.59930	0.22210
FC	14.89	13.87	14.81	14.03	Ŷ = 14.40	12.105	0.50521	0.82781
CY (%)	50.89	50.12	49.96	50.41	Ŷ = 50.34	4.303	0.61187	0.37970

IBW initial body weight, *FBW* final body weight, *ADG* average daily gain, *FC* feed conversion (kg DM per kg of gain), *CY* carcass yield (kg DM/kg Meat); *CB00* without castor bean meal; *CB30,* 290 g/kg of castor bean meal; *CC60,* 613 g/kg of castor bean meal; *CC90*, 903 g/kg of castor bean meal.

with 45% N), the response at the nitrogen fertilization permitted to obtain 62.78 kgDM per each Kg of Nitrogen application in all experimental period. This response is according with the results related by the literature, has been observed responses between 40 to 70 kg DM by kg of Nitrogen application (Fernandes et al., 2010). According to the observed, it is demonstrated that systems well managed with a rotational stocking rate on forage Marandu, and fertilized, is capable to produce high quantify of DM with more homogeneity, and to decrease the seasonal effects on the weight gain in grazing cattle.

The pdDM variable allows a better assessment of the forage, as it integrates its qualitative and quantitative aspects, thus representing the real carrying capacity of a pasture. according to the established animal performance goals (Paulino et al. 2008). The average pdDM found in this study was 4927.1 kg/ha, or 78.64% of TDM_A, which indicates a high fraction of the forage available to be digested. On average, this value corresponds to 3.91% of the animals' BW, meaning that neither their intake nor genetic expression was limited. This result is close to the 4–5% BW recommended by Paulino et al. (2004) as the minimum pdDM in continue stocking rate.

Forage mass, which represents the sum of the morphological components (green leaves + stems + sheaths), averaged 3832.80 kg/ha. This value is higher than the minimum of 1200 kg/ha recommended by Silva et al. (2009). Leaf:stem ratio was 0.91, which is within the range reported in the literature. Schio et al. (2011) found an L:S of 0,51, whereas Paula et al. (2012) found a ratio of 1.83 in *Brachiaria brizantha* cv. Marandu during the rainy season. As described by Santos et al. (2011), this measurement is associated with the availability of quality forage to meet the animal requirements, since the leaf fraction contains the highest concentrations of digestible energy, CP, and minerals. Therefore, importance should be attached to grazing management to ensure that the animal will consume a greater proportion of leaf blades.

Stocking rate was 2.86 AU/ha, which provided an average FA of 14.31% BW. This rate is higher than the 12.00% BW found by Zervoudakis et al. (2010), in *Brachiaria brizantha* cv Marandu under a rotational stocking rate in the rainy-dry transition period, in this indication provided adequate condition that permitted the forage selection and to express its maximum intake potential by the animal. The forage offered to the animals in this experiment is considered of good quality, since it showed an average CP content of 9.90% during the period (Table 2), which is higher than the minimum of 7% recommended by Lazzarini et al. (2009), for the growth and development of rumen microorganisms.

An important factor for the availability of forage was the occurrence of rainfall during the experimental period, which favored shoot emergence and tillering and, consequently, an increase in plant growth. Precipitation was highest in the month of March, which provided forage availability for the month of April (at the beginning of the experiment). In May, rainfall began to increase again, becoming more pronounced in June and July and finally decreasing in August (end of the experiment). The average rainfall during the experimental period was 44.3 mm, and the average annual rainfall in the region was 66 mm. Figure 2.

According to Tonato et al. (2010), pasture productivity can be affected by the variety of cultivars, temperature, precipitation, and incidence of light. However, climatic variables can be correlated, so another determining factor for the growth of the pasture in this study were the temperatures recorded, which averaged 22.89 ºC, with a minimum of 21.24 ºC and a maximum of 25.38 °C (Fig. 2). However, the ideal temperature for the growth of *Brachiaria* grasses is 30 to 35 °C. Mendonça & Rassini (2006), and Guimarães et al. (2007) observed basal temperature value of 15.0 °C and 16.3 °C, respectability, for the Marandu cultivar without influence in the growth.

Nutrients Intake

In this respect, there was a correlation between DM availability and the temperatures, with forage production being proportional to the temperatures recorded during the experimental period, the value represented 643 kg DM per temperature unit in °C (Fig. 3). According to Silva et al. (2012), the DM production increased when the temperature reached higher values, while the lowest DM production was observed when the temperature presented minimum values, according with the authors it is possible to assume that temperature may have affected plant physiology during the process of absorption and translocation of nutrients. The data obtained allow us to infer that the thermal unit can be used to estimate the dry matter of Marandu forage studied, due to the high coefficient of determination observed between these variables.

As regards the composition of the diet, the CP content decreased with the inclusion of CBM due to the lower levels of CP present in the by-product. The NDFap and iNDF contents, on the other hand, increased from 60.58 to 61.26% and 18.61 to 21.36%, respectively, with the inclusion of CBM.

The average daily forage DM intake was 8.56 kg, which, added to the supplement DM intake of 1.85 kg, resulted in an average total DM intake of 10.41 kg. When expressed relative to the animals' BW, these values corresponded to 1.93, 0.42, and 2.36% respectively. In this regard, we can infer that the entire supplement provided was consumed by the animals, regardless of the treatment. Total DM intake in %BW was close to the 2.48% found by Araújo et al. (2021) in pasture-finished crossbred steers supplemented with increasing levels of CBM replacing SBM.

Organic matter intake was same for all animals, averaging 9.50 kg/day. This result was similar to the 9.37 kg/day found by Diniz et al. (2011), who also reported no differences with CBM replacing by SBM 0, 330, 670, and 1000 g/kg in the diet of grazing beef cattle.

On the other hands, Detmann and Valadares Filho (2010), reports that after the first rains the fodder presents high concentrations of the NNP in CP and high digestibility of OM, so the fodder in this period is not considered deficient in nitrogen, which can be reflected in an increase in CMO by the animal. Considering that the beginning of this study was marked by rains, where the good forage intake with the addition of diet supplement explains the lack of effect on OMI by the animals, since all animals consumed the same amount of supplement. However, Matos et al. (2018), evaluating levels of replacement of CBM by SBM (0, 200, 500, 750 e 1000 g/kg of SBM with CBM at 0.7 kg/100 kg BW) for grazing heifers, reported decreased in the OMI, when the levels of supplementation were increased, the author attributes this effect on the reduction of forage intake that was low during the dry season.

Crude protein intake (kg/day) decreased ($P < 0.05$) by 0.0018% with each additional 1% CBM included in the diet. This result was possibly due to the reduction in the protein content of the total diet caused by the increasing levels of CBM. According to a study by Silva et al. (2009), the quantity and quality of forage and supplement supplied directly influence the intake of supplemented grazing animals. In view of this statement, it is suggested that, in association with the supplement, the forage CP content of 9.90% provided an average CP intake by 13.49% of the total diet (Table 4). This allowed the complete utilization of nutrients and total DM, since this value was higher than the minimum 6–8% CP recommended for the growth and development of ruminal microorganisms and to favor fibrolytic microbial activity, thereby allowing full capacity to utilize the fibrous components of the diet (Lazzarini et al., 2009).

The intake of NDFap did not differ between the treatments ($P > 0.05$), averaging 5.83 kg/day, which represents 1.25% BW. This value is lower than 1.35% suggested by Detmann et al. (2003) to prevent restrictions in DM intake by physical mechanisms in cattle in tropical conditions. It is also lower than the 1.8% BW that can be achieved by animals grazing on *Brachiaria* grasses during the dry season (Barbosa et al., 2007). Van Soest (1994) reported that the NDF of the diet is related to the space occupied by feed in the rumen and expresses the filling capacity of this organ. Silva et al. (2010) found NDF intakes of 1.61, 1.41, 1.11, and 0.98% BW, respectively, at the supplementation levels of 0, 0.3, 0.6, and 0.9% BW, in tropical conditions, and described no differences in nutrient intake by animals on *Brachiaria brizantha* pasture with an average availability of 3655 kg/ ha.

Although the increasing levels of CBM replacing SBM increased the iNDF content of the diets (2.75% more in the treatment with 903 g/kg replacement), this did not interfere with the intake of this fraction because the supplement was provided at 0.4% BW, on average, representing a CBM content of 4,25% at the maximum replacement level in the total diet. In this respect, Barros et al. (2011) also did not find a significant effect on NDF intake following the replacement of SBM with CBM, when CBM content in the total diet was 8% at the maximum replacement level.

According to Oliveira et al. (2010a, b), despite the larger indigestible fraction of NDF in CBM (about 66% NDF), the rapid degradation of the potentially degradable fraction (pdNDF) and the small size of the indigestible particle of NDF facilitated the processes of rumen disappearance of CBM and NDF, which may explain the lack of effects.

Sampaio et al. (2009) stated that when the CP content is greater 10%, the NDF substrate is used with greater efficiency. In this study, CP represented 13.49% of the diet, on average. This value is higher than the threshold (7—8%) suggested by Lazzarini et al. (2009) for the optimization of forage utilization, and, for this reason, there were no differences in NDFap intake across the replacement levels.

Ether extract intake decreased ($P < 0.05$) by 0.002% with each additional 1% CBM included in the supplement, a behavior likely related to the EE content of the supplement. However, the animals consumed equal amounts of supplement and its EE content was low, EE intake was also low. This was expected, given the lower concentration of this nutrient in CBM.

Palmquist and Jenkins (1980) suggest that an EE content of 6.0% DM is the maximum limit capable of inhibiting the growth of rumen microorganisms and coating the fiber of the feed, thereby reducing its digestion and also DM intake. Nonetheless, the percentages found in this study were below this limit (3.04, 3.02, 2.88, and 2.88% of the treatments involving 0, 290, 613, and 903 g/kg DM replacement, respectively, on a diet DM basis). Even though the values were higher, the decrease in EE intake was evident, which was due to the reduction in the EE content of the total diet as a consequence of the increasing concentrations of CBM replacing SBM. However, Matos et al. (2018), reported non differences in the EE intake values, in an experiment evaluating the replacement level of 1000 g/kg of SBM with CBM for grazing heifers, supplemented at 0.7 kg/100 kg BW.

The intake of NFC did not differ between the animals, averaging 1.98 kg/day. This result is superior to those found by Barros et al. (2011) in grazing heifers receiving supplemental in up to 1000 g/kg of SBM replaced with CBM, the authors described as quadratic behavior, with a maximum NFC intake of 1.72 kg/day occurring at the replacement level of 904.7 g/kg.

There was no difference in TDN intake across the tested levels of replacement in the supplement. The animals consumed on average 5.13 kg/day. According with NRC-National Research Council (2000), 1 kg TDN = 4.409 Mkal of digestible energy and 82% are metabolizable energy, in that sense, in this diet was proportioned 22.618 Mkal DE and 18. 546 Mkal ME, which is a higher value than the 17.600 Mkal ME recommended by Marcondes et al. (2016), for to provide the energy required of grazing crossbred beef steers. However, Barros et al. (2011) found lower values, describing an average TDN intake of 3.82 kg/day by grazing heifers fed a supplement in which CBM also replaced SBM without effect on the performance.

Digestibility

The digestibility of DM determines the use of the nutrients supplied to animals, both in terms of the amount that is digested and in differences or limitations they may exhibit. In this respect, the DM digestibility results found in this study did not differ between the treatments, averaging 49.51%. This value is close to the 42% reported by Diniz et al. (2011) in feedlot cattle fed a concentrate in which SBM was also replaced with CBM. Araújo et al. (2021) also described no differences in DM digestibility following the replacement of SBM with CBM, with an average of 66.52%, but the authors supplemented finishing steers on pasture at 0.5% BW.

Organic matter digestibility also did not differ between the replacement levels, averaging 53.45%. This is explained by the same formulation of the diets and their similar OM contents, coupled with the fact that OM intake did not change with the increasing CBM levels. Therefore, we may state that the diets containing CBM likely did not provide a low energy uptake, since they did not reduce the synchronism and, consequently, the synthesis of rumen microorganisms.

The decrease observed in CP digestibility is inferred due the increasing iNDF content in the diet provided by the growing concentrations of CBM. The average iNDF content found in our study was 45.11%; however, according to Oliveira et al. (2010a, b), the iNDF content of CBM may be higher than 60%. In addition, part of the protein oilseed by-products is unavailable, which can reduce the digestibility. Matos et al. (2018) found a reduction in CP digestibility, which declined by 0.494% with each percentage unit of CBM added to the supplement to replace SBM (from 0, 200, 500, 750 to 1000 g/kg) for grazing heifers supplemented at 0.7 kg/100 kg BW.

On the other hand, castor seed meal has an effective rumen degradation of intermediate crude protein among soybean meal and cottonseed meal, which explains the reduction in digestibility of crude protein as the levels of castor bean meal in the supplement increased (Moreira et al., 2003; Barros et al., 2011). With respect to NDFap, its digestibility was expected to decrease in response to the increasing NDFap contents in the diet provided by the inclusion of the by-product. Nevertheless, no such response occurred, which is possibly because the alkaline treatment improved the rate of ruminal degradation (Oliveira et al., 2010a, b) of the potentially degradable fraction of NDF. According to Araújo et al. (2021), the similar digestibility of NDFap can be easily explained by the standardized processing of CBM, which first undergoes a heat treatment for oil extraction, followed by the use of chemical solvents.

Ether extract digestibility did not change with the treatments, and, coupled with its lower intake and concentration in the diet; there was less release of this nutrient to the animal. Barros et al. (2011), on the other hand, described a 0.0509% increase in EE digestibility with every additional 1% CBM included in the diet.

The increased NFC digestibility may be linked to the composition of CBM, since each additional 1% CBM included in the supplement caused this variable to increase by 0.1249%. This result is inferred to be related to the NFC content of the supplement, as the amount of NFC in the diet increased proportionally with the CBM levels. Moreover, supplementation did not lead to differences in the intakes of OM and DM. In this regard, Barros et al. (2011) tested the replacement of SBM with CBM at 0, 330, 670, and 1000 g/kg DM and found that NFC digestibility increased linearly, by 0.0294% with each 1% CBM included in the supplement. According with the authors, these results are attributed to the intake of the supplement of the animals, which improved the digestibility of DM, OM, CP, EE, and NFC, resulting in a higher ADG in these animals compared with their non-supplemented counterparts.

The proportion of TDN in the diets did not vary between the treatments, averaging 48.34%. This finding can be attributed to the fact that DM digestibility did not differ with the increasing levels of CBM as a replacement of SBM in the diet. Conversely, Barros et al. (2011), found a quadratic effect in %TDN, with a minimum value of 63.80% found at the CBM level of 920 g replacing SBM. The authors attributed this result to the observed difference in DM digestibility between the treatments.

Performance

Animal performance is a result of the intake, digestibility, and the metabolism of nutrients extracted from the diet. According to Reis et al. (2016), the dry matter (DM) intake is a factor of extreme importance, more impacting on the animal performance than the relation to the concentration of nutrients of the forage. Silva et al. (2009) stated that with low DM intakes possibly affecting daily weight gain. When it comes to digestibility, Mertens (1992) mentioned that it influences at least 10 to 40% of body weight gain.

Therefore, the replacement of soybean meal with DCM did not influence the ADG which averaged 0.73 kg/day, possibly due to the adequate intake of protein and energy provided and digestibility by the diets including DCM. Ribeiro Lima et al. (2022) also did not observe an effect on the performance of grazing steers supplemented with CBM as replacement SBM including levels up to 280 g/ kg DM. Nevertheless, this value (0.73 kg/day) is lower than expected, since the diet was formulated to provide an ADG of 1 kg/day, which can be attributed to the genetic factor. With the animals used, it was not possible to achieve the expected gains. In this context, many authors point out that the conditions in which beef cattle are raised in the early stages can compromise their future performance and viability.

On the other hand, this value (0.730 kg/day) is within the range reported in the literature for crossbred cattle on pasture, e.g., Signoretti et al. (2012) and Sampaio et al. (2017), obtained an ADG of 0.382 and 0.70 kg/day in grazing crossbred cattle supplemented with cottonseed and energy-protein supplement, respectably, during the dry season. Consequently, Barros et al. (2011) and Araújo et al. (2021) reporting satisfactory production performance results in beef cattle on *Brachiaria decumbens* pasture, replacing CBM by SBM (0.500 and 0.975 kg/day, respectably), while receiving supplement up to 1000 g/kg CBM replacing SBM.

These results can also be attributed to the protein content provided by the inclusion of CBM in the supplement, which varied from 12.99 to 14.59%. And although the digestibility of CP decreased as the supplementation levels were increased, it exceeded the protein requirement of 11% of grazing beef cattle as established by the NRC-National Research Council (2016). Additionally, the forage available to the animals was of good quality and complied their requirements, since there was no difference between the ADG of the animals that were supplemented with CBM and those supplemented only with SBM.

The good pasture yield is due to its quality, management, and the rainfall that occurred at the beginning and throughout the experimental period, for this reason, the ADG found in this study 0.730 kg/d is according with the average reported in a meth analyses study realized by Tambara et al. (2021), where the authors found ADG as 0.590 kg/d in the dry and wet seasons with energy-protein supplementation provided at 0.1 to 0.49% BW and 0.710 kg/d when the supplementation was provided at 0.5 to 0.99% BW. That's why we can decide that protein supplementation with CBM in the present study reports a good weight gain according to the Brazilian average.

The feed conversion (FC) related the kilograms of DM necessary to produce 1 kg of meat, in this study was the value of FC was equal with all animals, being necessary 14. 40 kg of DM for to produce 1 kg of meat. This result is due to a good forage allowance and the supplement, that promoted a positive effect on the performance, considering the 2.14 AU/ha, the value is accepted. However, Silva et al. (2010), evaluating different levels of energy-protein supplementation of finishing Nellore steers in the dry season period (0, 0.3, 0.6 and 0.9% BW), found increased linearly on FC (20.75, 18.08, 14.73 and 13.64 kg of DM/kg meat produced), when the levels of supplementation increased, the quantify of dry matter necessary for to produce 1 kg of meat was decreased.

According to Fernandes et al. (2010), the production of meat depends on the number of animals on the pasture and the weight gain that has relationship to quality of forage, but in supplementation management, this is not prejudiced because the supplemental support to correct the deficiencies of nutrients of forage.

Carcass yield averaged 50.34%, which is within the range of 45–50% found in the literature and higher than the 47.70% found by Pimentel (2018). In an experiment realized by Rezende et al. (2012) utilizing crossbred animals also finished on *Brachiaria brizantha* pasture and supplemented at 0.5% BW, found a carcass yield of 48.62%, this value is similar to that of this research.

Conclusion

Detoxified castor bean meal can replace up to 903 g/kg DM of soybean meal in the supplement provided to grazing crossbred steers in the finishing phase during the rainy-dry transition period, without prejudice to animal performance.

Credits

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Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Conflicts of Interest I declare that there is not conflict of interest between the authors of the article **"Finishing of grazing steers supplemented with detoxified castor bean meal (Ricinus communis L.) in the rainy-dry transition period"** submitted for consideration in the Journal Tropical Animal Health and Production.

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