












Licuri cake as an alternative feed for young Nelore bulls replacing soybean meal and ground corn

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ABSTRACT - This study aimed to evaluate the effects of total replacement of soybean meal and partial replacement of ground corn with licuri cake (LC) in the diet of young Nelore bulls on feed intake, ingestive behavior, nutrient digestibility, nitrogen balance, microbial protein synthesis, animal performance, carcass traits and economic efficiency, including marginal costs and returns. Thirty-two 16-month-old Nelore bulls (346 ± 32.5 kg body weight) were individually evaluated in a completely randomized experimental design with four treatments (0, 7, 14, and 21% dry matter [DM]) and eight replications. The animals were feedlot-finished for 84 days, fed a diet consisting of 60% Tifton-85 hay as roughage and 40% concentrate mixture. The concentrate included ground corn, soybean meal, urea, ammonium sulfate, and mineral mixture. The inclusion of LC in the bulls' diets linearly reduced ($P < 0.05$) the intake of DM, crude protein (CP), neutral detergent fiber (NDF), total digestible nutrients (TDN), and nitrogen, as well as fecal N, urinary N excretion, and N retention. On the other hand, LC inclusion quadratically increased ($P < 0.05$) ether extract (EE) intake and microbial protein synthesis. In addition, there was a linear increase ($P < 0.05$) in the digestibility of CP, EE, and NDF, as well as in the percentage of bone, muscle, and muscle tissue:fat tissue ratio in the young bulls. In contrast, animal performance, hot and cold carcass weights, fat tissue content, diet cost, and financial returns linearly decreased ($P < 0.05$). Based on the levels tested, the inclusion of LC in bulls' diets is not recommended, as it reduces feed intake, performance, and overall financial profitability of the activity.

Keywords: alternative protein, byproduct, microbial efficiency, *Syngnus coronata*

1. Introduction

Byproducts generated from renewable energy production can be incorporated into ruminant diets, offering a sustainable solution for managing these compounds and reducing environmental waste

(Pinto et al., 2022), thereby reducing animal feed costs. One approach to lowering these expenses is to replace conventional feed ingredients with alternative, more affordable sources of protein and energy, while maintaining animal performance (Drumond, 2007; Aemiro et al., 2018; Nath et al., 2023).

One such alternative feed for ruminant nutrition is licuri cake (LC), which derives from the oil extraction from licuri nuts. The licuri palm tree (*Syagrus coronata*) is native to the Caatinga biome and is characterized by its medium size. It typically starts fruiting at around six years of age, with an average production of 2,000 to 4,000 kg/ha/year of fruits (coconuts) (Drumond, 2007). The fruits contain liquid when green and become solid and produce nuts when ripe (Crepaldi et al., 2001; Drumond, 2007). Licuri cake has been evaluated in ruminant diets by Lima et al. (2015), who found that it has a beneficial energy source for lactating cows on managed pastures. In that same study, the authors observed that providing 45 g of LC per kg of concentrate would lead to an increase in the digestibility of ether extract (EE) and dry matter intake (DMI).

Bagaldo et al. (2019) recommended the replacement of soybean meal in concentrate for grazing lambs with 17% LC in the DM because it increased the time spent eating, final weight, and average daily gain (ADG) of animals. Oliveira et al. (2022) recommend the inclusion of up to 25.5% LC in the diet of feedlot steers fed high-concentrate diets because it improved performance and carcass traits. Costa et al. (2019) observed that including LC up to the level of 24%, decreases operation costs, which in turn results in higher profitability.

However, LC has a high protein content (222 g CP/kg DM), in comparison with other biodiesel byproducts, as well as high EE (61 g EE/kg DM) (Bezerra et al., 2013; Bagaldo et al., 2019; Oliveira et al., 2022). In terms of carbohydrate fractionation (Silva et al., 2021; Van Soest, 1994), LC contains 520 g/kg of sugars (fraction A), starch, and soluble fiber compounds (fraction B1), which make it a potential substitute for commonly used protein and energy ingredients such as soybean meal and ground corn.

Nevertheless, the high fat content in LC may hinder rumen microbiota efficiency and reduce fiber digestibility (Behan et al., 2019), leading to decreased sheep performance. Therefore, we hypothesized the total replacement of soybean meal by LC (up to 21% of total mixed ration) and the partial replacement of ground corn in the diet of young bulls would reduce feed costs without negatively impacting animal performance. Thus, the objective of this study was to evaluate feed intake, ingestive behavior, nutrient digestibility, nitrogen balance, microbial protein synthesis and its efficiency, animal performance, carcass traits, and diet profitability in young Nellore bulls fed LC diets.

2. Material and methods

This study was conducted in accordance with the guidelines of the National Council for the Control of Animal Experimentation. All procedures were approved by the Ethics Committee on Animal Experiments of the Federal University of Bahia (case number: 16/2014).

2.1. Location, animals, and diets

The study was conducted at the Veterinary Medicine and Animal Science Experimental Farm of the Universidade Federal da Bahia, in São Gonçalo dos Campos, Bahia, Brazil (Latitude: -2.351062023637267, Longitude: -38.88197356995201). Thirty-two 16-month-old Nellore bulls, initially weighing 346 ± 32.5 kg of body weight (BW) were individually housed in partially covered 2×4 m stalls with concrete flooring equipped with individual feeders and water troughs. The experimental phase lasted 84 days and was preceded by a 15-day adaptation period to allow the animals to adjust to their environment, management practices, and diets. During this adaptation period, the cattle were vaccinated (Ivomec Pour-On Parasiticide, São Paulo, Brazil) and dewormed (Zoetis Animal Health Bovi-Shield Gold IBR-BVD, São Paulo, Brazil). Diets containing LC were introduced gradually, with the respective treatment levels progressively increased until the final inclusion level was reached for each experimental group.

Throughout the experiment, the bulls were provided a total mixed ration, offered twice daily at 09:00 and 16:00 h. Daily feed allowances were adjusted to ensure a 10% refusal rate, providing sufficient feed for *ad libitum* intake. Additionally, the bulls had unrestricted access to fresh water at all times.

The diets were formulated to maintain iso-nitrogen levels and fulfill the nutritional requirements of the young bulls, targeting an estimated weight gain of 1.20 kg/d, as per the recommendations outlined by the NASEM (2016). Tifton-85 hay served as the roughage component (40%, chopped to 2.00 cm in length), while the concentrate mixture (60%) contained ground corn, soybean meal, urea, ammonium sulfate, and mineral mix. Licuri cake was included in the diets at levels of 0, 7, 14, and 21% DM, replacing soybean meal and ground corn (Tables 1 and 2).

Table 1 - Mean and standard deviation (\pm SD) of chemical composition of ingredients analyzed in experimental diets offered to Nellore bulls

Item (%DM)	Ingredient of diets			
	Ground corn	Soybean meal	Licuri cake	Tifton 85 hay
Dry matter (% as fed)	89.2 \pm 1.32	93.0 \pm 1.45	92.7 \pm 1.33	91.2 \pm 1.68
Crude protein	8.58 \pm 0.98	50.1 \pm 4.32	23.0 \pm 1.99	5.10 \pm 0.09
Ether extract	4.39 \pm 0.11	1.87 \pm 0.08	15.7 \pm 0.22	1.13 \pm 0.03
Non-fiber carbohydrates	74.7 \pm 5.22	26.0 \pm 1.73	29.5 \pm 1.95	12.5 \pm 1.01
Acid detergent fiber	3.73 \pm 0.09	7.72 \pm 0.83	29.1 \pm 1.75	38.0 \pm 2.22
NDFap	13.1 \pm 0.99	15.6 \pm 1.01	51.9 \pm 4.23	75.2 \pm 5.43
Ash	1.22 \pm 0.06	6.40 \pm 0.65	6.51 \pm 0.71	6.08 \pm 0.62
Total digestible nutrients ¹	80.1 \pm 7.43	81.1 \pm 6.78	65.0 \pm 7.34	54.7 \pm 6.66

NDFap - neutral detergent fiber corrected for ash and protein.

¹ Estimated from the NRC (2001) equation.

Table 2 - Mean and standard deviation (\pm SD) of ingredient proportions and composition of analyzed experimental diets offered to Nellore bulls

Ingredient (%DM)	Licuri cake (%)			
	0	7	14	21
Tifton 85 hay	40.0	40.0	40.0	40.0
Licuri cake	0.00	7.00	14.0	21.0
Soybean meal	8.0	60.0	30.0	0.00
Ground corn	49.8	44.8	40.8	36.8
Mineral mixture ¹	1.0	1.0	1.0	1.0
Urea + ammonium sulfate ²	1.2	1.2	1.2	1.2
Chemical composition (%DM)				
Dry matter (% as fed)	90.5 \pm 1.29	90.7 \pm 1.33	90.8 \pm 1.03	90.9 \pm 1.49
Crude protein	12.8 \pm 1.20	12.8 \pm 1.23	12.8 \pm 1.17	12.8 \pm 1.15
Ether extract	2.79 \pm 0.61	3.62 \pm 0.46	4.48 \pm 1.50	5.35 \pm 1.67
Non-fiber carbohydrates	44.3 \pm 4.09	40.2 \pm 5.56	36.7 \pm 6.95	33.1 \pm 7.54
Acid detergent fiber	17.7 \pm 2.63	19.4 \pm 3.38	21.0 \pm 4.76	22.7 \pm 3.49
NDFap	37.9 \pm 5.07	40.5 \pm 8.16	43.2 \pm 9.45	45.8 \pm 9.34
iNDF	12.6 \pm 1.43	13.4 \pm 1.12	14.2 \pm 1.32	15.0 \pm 1.23
Ash	4.55 \pm 1.20	4.82 \pm 0.44	5.03 \pm 0.71	5.25 \pm 0.56
Total digestible nutrients	68.3 \pm 5.34	67.2 \pm 5.87	66.1 \pm 5.88	65.0 \pm 6.01

NDFap - neutral detergent fiber corrected for ash and protein; iNDF - indigestible neutral detergent fiber.

¹ The guaranteed levels of active elements per kilogram are as follows: calcium, 220.00 g (maximum) - 209.00 g (minimum); phosphorus, 163.00 g; sulfur, 12.00 g; magnesium, 12.50 g; copper, 3500.00 mg; cobalt, 310.00 mg; iron, 1960.00 mg; iodine, 280.00 mg; manganese, 3640.00 mg; selenium, 32.00 mg; zinc, 9000.00 mg; with a maximum fluoride content of 1630.00 mg.

² The mixture contains urea and ammonium sulfate in a 9:1 ratio.

2.2. Licuri cake production process

The LC used was acquired directly from the company Lipe Indústria de Sabão e Velas Ltda. (Guanambi, Bahia, Brazil). It was obtained through a physical extraction process involving pressing and heating, in which the licuri nuts are macerated to facilitate oil extraction. The residual byproduct remaining after oil removal constituted the LC, which was mixed into the diet daily.

2.3. Feed intake and ingestive behavior

Throughout the experimental period, leftover feed was gathered and weighed daily to measure the animals' daily intake. To assess the ingestive behavior of the animals, individual observations were conducted on three days (days 25, 46, and 60) at 10-minute intervals, aligning with the recommendation of Martin and Bateson (1993). Each animal was subject to 864 observations. Trained observers recorded the specific behaviors of each animal, ensuring minimal interference. The recorded behavioral variables included the duration (in minutes per day) of eating, rumination, and idleness. Additionally, eating rate (DM) and rumination rates [DM and neutral detergent fiber (NDF)] were calculated as the ratio of DM or NDF intake (kg) to the time spent eating or ruminating (hours), following the methodology described by Bürger et al. (2000).

2.4. Digestibility trial, microbial protein efficiency, and nitrogen balance

Feces were collected over seven consecutive days (from day 36 to 42 of the experimental period). Two samples were taken daily at 08:00 and 16:00 h, after the total mixed ration delivery, directly from the animals' rectum. These samples were then combined into a composite sample, as recommended by Cavallini et al. (2023). Fecal samples were promptly subjected to oven drying at 55 °C for 72 h and were ground using a Wiley-type mill (model 3, Arthur H. Thomas, Philadelphia, PA), through a 3-mm screen.

Indigestible neutral detergent fiber (iNDF) was used as an indicator according to method outlined by Valente et al. (2011a). For this procedure, samples of the diet, feces, and refused feed (20 mg DM/cm²) were packed in nonwoven bags (pore size of 23 µm; Vivatex®, São Paulo, Brazil), and placed in the rumen of two young fistulated bulls (372 ± 35.1 kg and initial age of 23 months) for incubation over 288 h (Valente et al., 2011b). Subsequently, the residues from incubation were rinsed until the water ran clear and then dried under forced ventilation at 55 °C for 72 h. Then the iNDF content was determined (Van Soest et al., 1991). Fecal production (kg DM/d) was estimated by dividing the total amount of ingested indicator by the concentration of the indicator in the feces.

The apparent digestibility coefficients (DC) of DM, CP, EE, NDF, and non-fiber carbohydrates (NFC) were computed using the following equation: $DC = (\text{kg of portion ingested} - \text{kg of portion excreted}) / (\text{kg of the portion ingested}) \times 100$.

The total digestible nutrient (TDN) intake was calculated according to Sniffen et al. (1992). The concentrations of TDN in the diet were obtained by the equation: $\text{TDN (g/kg)} = (\text{intake of TDN}) / (\text{intake of DM}) \times 100$.

Urine samples were collected over 4 h following the morning feeding. Special plastic collectors, tailored to fit the animals' bodies, were utilized for urine collection. The collected urine underwent filtration, and a 10-mL aliquot was diluted with 40 mL of stock solution (0.018 mM H₂SO₄) before being stored at -20 °C for subsequent analysis of creatinine, allantoin, and uric acid. Allantoin analysis was carried out using a colorimetric method (Chen and Gomes, 1992), while uric acid was assessed following the procedure outlined by Fossati et al. (1980). The creatinine concentration was determined using the alkaline picrate method, employing commercial kits (Labtest® Diagnostics SA, Minas Gerais, Brazil) and an Auto Analyzer II (In Vitro Diagnostics, Itabira, MG, Brazil).

The daily urine volume excreted by each animal was estimated by multiplying its body weight (BW) by the amount of urinary creatinine excretion (UCE) and then dividing the product by the creatinine concentration (mg/L) in the spot sample (Chizzotti et al., 2008). The UCE in zebu cattle can be approximated using the shrunk body weight (SBW) through the equation (Costa e Silva et al., 2012): $UCE \text{ (g/day)} = 0.0345 \times SBW^{0.9491}$.

The quantity of absorbed microbial purines (X, mmol/day) was calculated from the excretion of purine derivatives (Y, mmol/day) using the following equation (Verbic et al., 1990): $Y = 0.85X + (0.385 \times BW)^{0.75}$, in which 0.85 is the recovery of purines absorbed as purine derivatives in urine and $0.385 \times BW^{0.75}$ represents the endogenous contribution to purine excretion. The intestinal flow of nitrogen microbial compounds (Y, g N/day) was calculated as a function of absorbed purines (X, mmol/day) using the equation of Verbic et al. (1990): $Y = 70X / (0.83 \times 0.134 \times 1000)$, in which 70 represents the N content in the purines (mg N/mmol), 0.83 represents the digestibility of microbial purines, and 0.134 represents the total N purine:N in bacteria ratio.

Nitrogen balance was computed as: retained N (g/d) = N intake – fecal N excretion – urinary N excretion. The efficiency of microbial synthesis (g N/100 g TDN) was determined by dividing the microbial protein synthesis by the TDN intake.

On the 35th day of the experiment, blood samples were obtained through jugular vein puncture and collected in Vacutainer tubes (Labtest® Diagnóstico SA, Minas Gerais, Brazil) containing the anticoagulant EDTA. These collections occurred 4 h after morning feeding. Immediately after collection, the samples were transported to the laboratory and centrifuged (model 80-2B DM, IonLab, PR, Araucária, Brazil) at $3000 \times g$ for 15 min to obtain plasma. Blood urea nitrogen (BUN) concentrations were determined by a commercial kit (Labtest® Diagnóstico SA, Minas Gerais, Brazil).

2.5. Chemical analyses

Laboratory analyses were conducted in triplicate to determine the chemical composition of the ingredients (Table 1), diets (Table 2), feed, leftovers, and feces, according to the guidelines outlined by the AOAC (2016). The concentrations of DM (method 967.03), CP (method 981.10), EE (method 920.29), and ash (method 942.05) were determined. Acid detergent fiber (ADF) and NDF were determined following the methodology proposed by Van Soest et al. (1991). For NDF analysis, three drops (50 µL) of thermostable α -amylase (Sigma-Aldrich, Darmstadt, Germany) were added per sample during washing with detergent and water. A portion of the NDF residue was incinerated in an oven at 600 °C for 4 h to correct for ash contamination, while another portion was used to correct for protein contamination (NDFap). The NFC content was determined according to Detmann and Valadares Filho (2010) as: $NFC = 100 - [\%CP + \%NDFap + \%EE + \%ash]$, using CP from urea.

2.6. Performance, slaughter, carcass traits, and tissue composition

The bulls were weighed every 21 days throughout the experimental period, initially to determine their initial BW and at the end, after a 16-hour fasting period, to obtain the slaughter BW. The ADG was computed by dividing the total weight gain (final BW – initial BW) by the number of days in the experimental period (84 days). Feed efficiency was calculated by dividing ADG by DMI, with values expressed in kg/kg.

Slaughter procedures followed the guidelines of the Federal Inspection Service, in compliance with the regulations of Normative no. 03/00, of the Ministry of Agriculture and Livestock (Brasil, 2000). After skinning and evisceration, carcasses were weighed to determine the hot carcass weight (HCW) before being stored in the cold chamber for 24 h at 4 °C.

Following cooling, carcasses were weighed again to obtain the cold carcass weight (CCW). Cooling losses (CL) were calculated as $CL = (HCW - CCW / HCW) \times 100$. Hot carcass yield (HCY) was determined as a ratio of HCW to the body weight at slaughter (BWS) in percentage by the equation:

HCY = (HCW/BWS) × 100; and the cold carcass yield (CCY) was calculated as CCY = (CCW/BWS) × 100. The gastrointestinal tract was weighed to determine the empty body weight (EBW) and the real yield (RY) from the equation of Osório and Osório (2005): RY% = (HCW/EBW) × 100.

At the HH rib section, corresponding from the 9th to 11th ribs, carcasses were sectioned to facilitate measurement of subcutaneous fat thickness (SFT) and *longissimus dorsi* muscle area (loin eye area, LEA) using a digital caliper. Loin eye area was calculated according to the following equation (Osório and Osório, 2005): LEA = [(C × La²)/2] × π, in which C = maximum length, La = maximum width, and π ≈ 3.1415. Muscle, bone, and fat proportions in the carcass were predicted in the same anatomical region, applying the equation described by Hankins and Howe (1946).

2.7. Marginal costs and returns

The analysis of marginal costs (related to diets) and returns from meat production involved a descriptive examination of the total cost of the diet over the 84-day experimental period, which was based on the current US dollar exchange rate (provided by Dairy Farm International Holdings LTDA.). Returns were calculated by determining the cold carcass weight (in kg) of the young Nelore bulls during the data collection period and scaling it to the total experimental duration, expressed as kg per animal over the 84-day period.

The gross margin from meat sales (in US\$ per bull per 84 days) was determined by subtracting the total feed cost (in US\$ per 84 days) from the total amount received for the meat (in US\$ per kg per 84 days). Economic returns (profit or loss) were expressed in US\$ per bull per day.

2.8. Experimental design and statistical analysis

The experimental design was completely randomized with four treatments and eight experimental units (bulls) per treatment, respectively. The following statistical model was used:

$$Y_{ij} = \mu + s_i + e_{ij}$$

in which Y_{ij} = observed value, μ = overall mean, s_i = effect of LC (0 for the control or 7, 14, and 21% of total DM), and e_{ij} = effect of the experimental error.

Variables were analyzed using the PROC MIXED procedure of SAS (Statistical Analysis System, version 9.4). The animal was considered as the experimental unit, and the effect of LC replacement was tested using linear and quadratic polynomial orthogonal contrasts. The significance level was set at a probability of 5% ($P \leq 0.05$).

To contribute to data homogeneity, when analyzing the growth performance and carcass trait data, the initial BW was used as a covariate for statistical analysis using the following model:

$$Y_{ij} = \mu + T_i + \beta(W_{ij} - W) + e_{ij}$$

in which Y_{ij} = observed value of the dependent variable (performance and carcass) in animal j receiving treatment i , μ = general mean, T_i = fixed effect of treatment i (i = effect of the LC inclusion), β = linear regression coefficient relative to covariate W_{ij} , W_{ij} = covariate effect (initial BW of animal j receiving treatment i), and e_{ij} = random effects in the experimental error.

Variables with repeated measures over time (ingestive behavior, urine, feces, digestibility) were analyzed according to the following model:

$$Y_{ijkl} = \mu + D_i + a_j + p_k + (Dap)_{ijk} + T_l + (DT)_{il} + e_{ijkl}$$

in which Y_{ijkl} = observed value, μ = overall mean, D_i = effect of substitution of soybean meal with LC, a_j = period, T_l = time, and e_{ijkl} = effect of experimental error. Polynomial contrasts (linear and quadratic) were used to examine the effects of treatments and time on the response variables. For all data, statistical difference was significant when $P \leq 0.05$. Homogeneity of variances was tested for $P = 0.05$,

and when significant, heterogeneity was adjusted in the model using the REPEATED command of PROC MIXED.

3. Results

3.1. Intake and ingestive behavior

The replacement of soybean meal and ground corn by LC linearly and quadratically decreased ($P < 0.001$) the daily intake of DM expressed in kg and g/kg BW, respectively (Table 3). However, a quadratic increase on the intake of NDFap g/kg BW was observed (Regression equation, $Y = -0.00704x^2 + 0.12386x + 3.337$), with maximum inclusion of 8.89% LC on DM basis.

Licuri cake inclusion did not affect the eating, ruminating or idling time (min/day). However, the inclusion of LC promoted a linear reduction in the eating efficiency (kg/h) of DM ($P < 0.001$) and in the ruminating efficiency (kg/h) of DM ($P = 0.004$) and NDFap ($P = 0.007$).

Table 3 - Intake and ingestive behavior of young bulls fed diets containing licuri cake

Variable	Licuri cake (%DM)				SEM	P-value	
	0	7	14	21		Linear	Quadratic
Intake (kg DM/d)							
Dry matter	10.1	9.80	9.15	6.29	0.27	<0.001	<0.001
Crude protein	1.37	1.35	1.24	0.85	0.04	<0.001	<0.001
Ether extract	0.32	0.39	0.44	0.36	0.01	0.005	<0.001
Non-fiber carbohydrates	4.88	4.15	3.40	2.12	0.19	<0.001	0.005
NDFap	3.39	3.70	3.85	2.78	0.09	0.003	<0.001
Total digestible nutrients	7.14	6.68	6.65	4.95	0.19	<0.001	0.002
Intake (g/kg final BW/d)							
Dry matter	20.0	20.5	20.4	14.6	0.50	<0.001	<0.001
NDFap	0.67	0.77	0.85	0.65	0.02	0.869	<0.001
Ingestive behavior (min/d)							
Eating	205	199	266	218	9.13	0.160	0.208
Ruminating	388	375	347	399	13.0	0.965	0.233
Idling	847	866	827	823	17.6	0.502	0.765
Rate							
Intake (kg DM/h)	3.30	3.18	2.01	1.74	0.18	<0.001	0.761
Rumination (kg DM/h)	1.77	1.74	1.50	0.95	0.11	0.004	0.175
Rumination (kg NDF/h)	0.85	0.83	0.72	0.45	0.03	0.007	0.257

SEM - standard error of the mean; NDFap - neutral detergent fiber corrected for ash and protein.

3.2. Digestibility, N balance, microbial protein synthesis and efficiency, and BUN

A linear increase was observed for the digestibility of CP ($P = 0.003$), EE ($P < 0.001$), and NDFap ($P < 0.001$) with the replacement of ground corn and soybean meal by LC (Table 4). The digestibility of DM and NFC was not affected. The replacement of soybean meal and ground corn by LC in the diets of the young bulls promoted a linear reduction in N intake, fecal N, urinary N, and total loss as g/d ($P < 0.001$), retained N as g/d and as % of N intake, and BUN ($P = 0.039$). However, a linear increase effect ($P < 0.001$) was observed for urinary N excretion as % of N intake. Microbial protein synthesis ($P = 0.002$) and microbial protein synthesis efficiency increased quadratically.

Table 4 - Digestibility and nitrogen balance of young bulls fed diets containing licuri cake

Variable	Licuri cake (%DM)				SEM	P-value	
	0	7	14	21		Linear	Quadratic
Digestibility (g/100 g ingested)							
Dry matter	64.9	63.9	64.1	66.9	5.19	0.171	0.071
Crude protein	72.3	70.5	76.3	77.2	8.29	0.003	0.332
Ether extract	82.3	83.4	90.7	94.9	10.3	<0.001	0.099
Non-fiber carbohydrates	79.1	79.5	77.9	80.4	7.76	0.759	0.519
NDFap	45.0	46.9	49.8	54.6	10.6	<0.001	0.414
Nitrogen balance							
N intake (g/d)	220	216	198	135	8.72	<0.001	0.232
Total N excretion (g/d)	125	117	108	94.5	7.34	0.033	0.465
Fecal N excretion (g/d)	59.8	54.1	47.2	37.1	4.96	<0.001	0.523
Urinary N excretion (g/d)	65.6	62.5	60.8	57.4	3.22	<0.001	0.228
Fecal N excretion (% of N intake)	27.2	25.0	23.8	27.5	2.45	0.324	0.674
Urinary N excretion (% of N intake)	29.8	28.9	30.7	42.5	3.09	<0.001	0.156
Retained N (g/d)	94.6	99.4	90.0	40.5	6.44	<0.001	0.054
Retained N (% of N intake)	43.0	46.0	45.5	30.0	4.12	<0.001	<0.001
Microbial protein production (g/d)	73.5	103.5	99.1	52.9	1.12	0.072	0.002
Microbial synthesis efficiency (g N/100 g TDN)	10.3	15.5	14.9	10.7	2.27	0.126	<0.001
Blood urea nitrogen (mg/dL)	20.5	22.6	18.6	17.9	0.37	0.039	0.121

SEM - standard error of the mean; NDFap - neutral detergent fiber corrected for ash and protein; TDN - total digestible nutrients.

3.3. Performance, carcass traits, tissue composition and diet profitability

The replacement of soybean meal and ground corn by LC in the diets of the young bulls resulted in linear decreases in total weight gain ($P < 0.001$), ADG ($P = 0.011$), and BWS ($P < 0.001$; Table 5). Feed efficiency did not change with the inclusion of LC, presenting a similar mean of 0.155 (kg/kg).

Table 5 - Performance, carcass traits, and tissue composition of young bulls fed diets containing licuri cake

Variable	Licuri cake (%DM)				SEM	P-value	
	0	7	14	21		Linear	Quadratic
Initial body weight (kg)	352	349	343	340	-	-	-
Final body weight (kg)	509	480	451	431	7.72	<0.001	0.612
Total weight gain (kg)	157	131	108	91.0	5.93	<0.001	0.292
Average daily gain (kg)	1.59	1.32	1.09	0.92	0.061	0.011	0.353
Feed efficiency ¹ (kg/kg)	0.13	0.16	0.14	0.15	0.014	0.422	0.382
Hot carcass weight (kg)	278	269	249	215	5.69	<0.001	0.001
Cold carcass yield (g/kg)	539	557	551	496	4.09	<0.001	0.071
Empty body weight (kg)	455	429	404	386	6.91	<0.001	<0.001
Real yield (g/kg)	609	627	620	558	6.83	<0.001	<0.001
Loin eye area (cm ²)	65.5	70.6	69.6	60.5	1.10	0.060	0.030
Subcutaneous fat thickness (mm)	5.94	5.88	4.56	3.63	0.35	<0.001	0.060
g/kg of carcass composition ²							
Bone	184	182	192	218	5.32	<0.001	0.191
Muscle	534	562	582	590	6.44	<0.001	0.351
Fat	282	252	224	192	8.23	<0.001	0.811
Ratios							
Muscle:bone	2.93	3.17	3.04	2.77	0.08	0.413	0.131
Muscle:fat	1.92	2.22	2.69	3.16	0.12	<0.001	0.642

SEM - standard error of the mean.

¹ Average daily gain: dry matter intake ratio.

² Estimated using HH section calculated according to Hankins and Howe (1946).

A quadratic effect was observed for HCW ($P < 0.001$), RY ($P < 0.001$), and SFT ($P < 0.001$) as the levels of LC increased. A linear decrease was observed for EBW ($P < 0.001$). The inclusion of LC resulted in a quadratic effect ($P = 0.030$) on LEA. Based on the polynomial equation $Y = -0.0007x^2 + 0.1293x + 65.4$, the maximum LEA of 71.2 cm^2 was estimated at an LC inclusion level of 89.3 g/kg .

The inclusion of LC increased the g/kg of bone ($P < 0.001$), g/kg of muscle ($P < 0.001$), and muscle:fat ratio ($P < 0.001$), while reduced the g/kg of fat ($P < 0.001$), and did not affect the muscle:bone ratio.

The use of LC replacing ground corn and soybean meal decreased the diet cost, which ranged from US\$ 254.78/ton (diet with soybean meal) to US\$ 219.18/ton (LC inclusion at 21% of total DM) (Table 6). However, at the end of 84 days, the weight of carcass of the animals fed the diet without LC made US\$ 197.44 more per bull, and the gross margin of meat sales per animal for 84 days was US\$ 97.08 greater when the bulls were fed the diet without LC compared with the 21% LC inclusion. The financial return showed a linear decrease due to LC inclusion, and young bulls fed soybean meal and ground corn (US\$ 8.02 animal/d) presented a return 16% greater compared with animals receiving 21% LC (US\$ 6.78 animal/d).

Table 6 - Marginal costs and returns of diets with licuri cake for young bulls and their meat yield

Variable ¹	Licuri cake (%DM)			
	0	7	14	21
Diet cost (US\$/ton)	254.78	245.18	232.18	219.18
Diet cost (US\$/kg)	0.25	0.25	0.23	0.22
Dry matter intake (kg/d)	10.1	9.8	9.15	6.29
Diet cost (US\$/bull/84 d)	216.16	201.83	178.45	115.81
Meat weight (@)	18.33	17.80	16.47	14.27
Sales price of @ of meat (US\$)	48.55	48.55	48.55	48.55
Returns (US\$/animal/d)	8.02	7.89	7.39	6.87

¹ Price in dollar quoted at R\$ 5.40.

4. Discussion

The inclusion of LC at 21% of the total dietary DM, entirely replacing soybean meal and partially replacing ground corn, resulted in a reduction of DMI by approximately 40%. This decrease is likely attributable to the lower fiber quality of the LC residue, which contains a significantly higher concentration of ADF (29.1% DM) compared with ground corn (3.73% of ADF) and soybean meal (7.72% of ADF). This observation is further supported by the increased iNDF content in diets with higher levels of LC inclusion, which accounts for approximately 50% of the dry weight of LC with very few calories (Sánchez et al., 2023). This energy associated with decreased CP intake may explain the reduction in DMI and animal performance. Another factor contributing to low energy intake was the decreased NDF intake and TDN. In addition, the substantial increase in EE content (approximately 100%) can alter the rumen fermentation pattern (Behan et al., 2019). Animals receiving 140 g/d LC in their diet should ideally ingest an average of 430 g/d fat, based on NASEM (2016) recommendations, which suggest that total fat intake should not exceed 0.96 g fat/kg BW. Another factor contributing to decrease DMI, and subsequent nutrient intake could be the fatty acid profile of LC that has a high concentration of medium-chain fatty acids (Bauer et al., 2013), which have a lower melting point, affecting microbial cell membrane stability, and impacting feed acceptability, thus reducing DMI (Hristov et al., 2011; Palmquist and Mattos, 2011).

Rumen degradable protein (RDP) is a protein that is available for use by rumen microorganisms. Most of the RDP is transformed into ammonia in the rumen, with a small part being proteolyzed to amino acids and small polypeptides used by microorganisms in the rumen (Bach et al., 2005; Putri et al., 2021). The reduction in CP and energy intake, even with the same proportion of protein in the diet,

can cause rumen bacteria to present protein deficiency (Brooks et al., 2012). This situation may occur if the sources have low protein degradability, and this may have occurred due to the higher concentration of protein bound to unavailable fiber in the LC, since the fiber quality of LC is worse ($>iNDF$) compared with corn grain and soybean meal, making N unavailable for rumen bacteria (Bach et al., 2005). As bacteria are mainly responsible for fiber degradation, the result is a reduction in the passage rate, an increase in rumen filling, and a consequent reduction in DMI (Das et al., 2014).

The reduced efficiency of feeding and rumination of DM and NDF when LC increased in the bulls' diet also occurred due the quality of dietary fiber, as evidenced in previous studies (Oliveira et al., 2022; Conceição Santos et al., 2024). Bagaldo et al. (2019) noted that fatty acids associate with hydrophobic surfaces of feed particles, explaining low-fat microbial toxicity when animals are fed roughage-rich rations, thus elucidating the reduction in DMI and rumination efficiency of DM and NDF. The lignification of cellulose and hemicellulose makes it difficult for rumen microorganisms to attack these components. According to Van Soest (1994) and Forbes (1995), ingestive behavior and digesta passage rate can modify nutrient digestibility.

The addition of LC into the bulls' diets led to a reduction in N intake, excretion, and retention. The nitrogen values observed in this study fell within the range reported for growing beef cattle fed grass silage-based diets (20 to 101 g/day; Yan et al., 2007) and for those offered diverse feed compositions (30 to 89 g/day; Salah et al., 2015). Nitrogen retention serves as an indicator of ADG in cattle, as noted in previous research. With approximately 750 g/kg of meat composed of water and 250 g/kg consisting of protein (Sánchez Chopa et al., 2016), and applying a nitrogen-to-crude protein conversion factor of 6.25, the estimated ADG for steers in this experiment varied from 920 to 1,590 g.

While the control group (0% LC) had higher N intake, animals consuming higher levels of LC showed an increase in urinary N excretion relative to nitrogen intake. This increase likely reflects the greater urine volume required to eliminate excess nitrogen (Knowlton et al., 2010). Using an estimated CP digestibility of 72% for grass (Orskov, 1988; Owens et al., 2008) and assuming an ADG of 1,250 g, the calculated CP requirements for maintenance and growth were approximately 770 g/day (NASEM, 2016). The CP supply in the diets ranged from 850 g/day in the 21% LC group to 1,370 g/day in the control group, exceeding the predicted requirements by 11 and 56%, respectively.

Nitrogen excretion through urine was notably higher than through feces, aligning with prior findings. In our study, urinary N excretion was 10 to 20% greater than fecal N excretion. These results suggest that dietary CP levels could be reduced to approximately 100 g CP/kg DM without negatively affecting animal growth, thereby substantially lowering nitrogen excretion, particularly through urine (Fanchone et al., 2013).

The urinary N excretion observed in this study ranged from 29.8 to 42.5% of N intake, which is consistent with previously reported values for beef cattle. Animals receiving 21% LC showed N excretion levels within the higher range, comparable to other studies testing similar conditions (Valadares et al., 1997; Bezerra et al., 2013).

When calculating ADG based on N retention, it is estimated that 30 g of N retention corresponds to 1 kg of ADG. Diets containing LC from 7 to 14% inclusion achieved an average microbial protein synthesis efficiency of 15 g N/100 g TDN, whereas the control and 21% LC diets averaged only 10.5 g N/100 g TDN. This efficiency falls below the recommended level of 13 g N/100 g TDN, as outlined by NASEM (2016).

Additionally, the decrease in BUN is beneficial as it can prevent economic losses resulting from excessive dietary protein supply and potential production and environmental losses (Yang et al., 2016). However, the BUN reduction observed may have been due to the increase in N bound to insoluble NDF ($iNDF$) with the addition of LC in the concentrate. Changes in BUN concentrations are correlated with rumen ammonia content, which depends on rumen microorganism metabolic activity converting N to ammonia into bacterial proteins (Rhoads et al., 2006).

The decrease in DMI and retained N led to decreased animal performance and carcass weights. These reductions in weight gain could represent economic losses since slaughterhouses typically compensate producers based on slaughter BW or carcass weight (Scholz et al., 2015).

The inclusion of LC up to 7% of total DM replacing soybean meal and ground corn in the diet of young bulls increased LEA that ranged from 65.5 (0% LC) to 70.6 (7% LC) cm², which is desirable as this variable directly relates to body composition, tissue development, and commercial meat cut yields (Silva et al., 2019). These LEA results are associated with increased CP digestibility, microbial protein synthesis, microbial protein synthesis efficiency, and retained N (g/100 g of N), which can enhance N compound availability for animal muscle deposition metabolism (Sniffen et al., 1992; Dewhurst et al., 2000). The average LEA (66.6 cm²) was similar to that reported by Eiras et al. (2014) in bulls and greater than the minimum recommendation (64 cm²; Yan et al., 2007), except in animals fed 21% LC inclusion (60.5 cm²). The average fat thickness was 5.0 mm, falling within the standard range for beef cattle (between 3.0 and 5.0 mm), with carcasses outside this range receiving penalties (Osório and Osório, 2005). However, it is noteworthy that the treatment with 21% LC inclusion showed the lowest average fat thickness (3.62 mm), approaching the acceptable limit for subcutaneous fat deposition, demonstrating a linear decrease in fat thickness deposition due to LC inclusion, which is directly linked to DMI, dietary energy content, and nutrient digestibility (Valadares et al., 1997; Silva et al., 2019), since more nutrients available for animal metabolism result in greater tissue deposition.

Our results revealed a significant reduction on the cost of feed consumed when the bulls were fed LC. As diet ingredient values indicated, lower marginal costs lead to higher returns and the best benefit-cost ratio with higher LC inclusion levels (US\$ 115.81/bull/84 d) than the control diets or soybean meal (US\$ 216.16/bull/84 d). However, the decreased DMI and performance reduced total meat profit (at 84 d), which ranged from 890.08 to 692.65 g/d. Although there were more significant savings in diet spending, the lower growth performance did not allow for a better financial return for animals fed LC. According to Salami et al. (2019), there is improved economic performance with increased integration of higher inclusion levels of byproducts (cake and waste) in cattle diets, which demonstrates sustainability and viability of byproducts as a promising alternative protein source to fill the nutrient gap in the animal feed industry (Malenica et al., 2023).

It is necessary to emphasize two key points: the first is that the LC used in the diets exhibited a distinct composition from what is typically reported in the literature. This disparity underscores the variability in byproducts and highlights the challenge of their consistent utilization in animal nutrition. While previous literature (Lima et al., 2015; Silva et al., 2021; Oliveira et al., 2022) depicts LC as a source of NFC, our analysis revealed a higher concentration of unavailable fiber (52% iNDF), when compared with ground corn (13.1% iNDF) and soybean meal (15.6% iNDF), and moderate fat content (15.7% EE), when compared with ground corn (4.39% EE) and soybean meal (1.87% EE), respectively (Table 1). The second point highlights the impact of LC inclusion on CP utilization, as previously discussed. This alteration manifests through reduced N intake, fecal N, and retained N, coupled with increased urinary N excretion. Such shifts significantly influenced the animal performance and consequently the financial return. These results highlight the importance of thorough analysis prior to incorporating byproducts into animal diets.

5. Conclusions

Replacing corn grain and soybean meal with LC at levels up to 21% of total DM in the diets of young Nellore bulls is not recommended, as it adversely affects feed intake, animal performance, and overall financial returns. Nevertheless, the lower cost of LC compared with traditional, more expensive feed ingredients could make it a practical alternative in situations where high feeding costs threaten the viability of livestock operations.

Data availability

The data supporting the findings of this study are available from the corresponding author upon request.

Author contributions

Conceptualization: Barbosa, A. M. **Data curation:** Silva, L. F.; Portela, R. W. D.; Lima, A. G. V. O. and Nascimento, T. V. C. **Formal analysis:** Silva, L. F.; Oliveira, V. S.; Portela, R. W. D.; Gouvêa, A. A. L.; Lima, A. G. V. O.; Nascimento, T. V. C. and Silva Júnior, J. M. **Funding acquisition:** Oliveira, R. L. **Investigation:** Barbosa, A. M. **Methodology:** Silva, L. F.; Oliveira, V. S.; Gouvêa, A. A. L. and Bezerra, L. R. **Project administration:** Oliveira, R. L. and Barbosa, A. M. **Software:** Silva, T. M. **Supervision:** Lima, A. G. V. O.; Nascimento, T. V. C. and Barbosa, A. M. **Writing – original draft:** Silva, L. F. **Writing – review & editing:** Silva, T. M.; Bezerra, L. R. and Silva Júnior, J. M.

Conflict of interest

The authors declare no conflict of interest.

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