



Effect of dietary inclusion of licuri cake on intake, feeding behavior, and performance of feedlot cull cows

Maria Luíza França Silva¹ · Gleidson Giordano Pinto de Carvalho² · Fabiano Ferreira da Silva¹ · Laize Vieira Santos¹ · Marceliana da Conceição Santos¹ · Ana Paula Gomes da Silva¹ · Arthur Santos Danieleto¹ · Talia da Cruz Silva Mandinga¹ · Tarcísio Ribeiro Paixão¹ · Dorgival Moraes de Lima Júnior³ · Robério Rodrigues Silva¹

Received: 23 February 2022 / Accepted: 29 July 2022 / Published online: 12 August 2022
© The Author(s), under exclusive licence to Springer Nature B.V. 2022

Abstract

Licuri cake (LC) is an interesting alternative nutritional component for high-grain diets for ruminants due to its high protein (21.6% CP), fat (12.0% EE), and fiber (62.8% NDF) contents. We investigated the effect of increasing levels of LC inclusion on the intake, digestibility, feeding behavior, performance, and carcass traits of cull cows fed high-grain diets. Forty Zebu cows with an initial weight of 318 ± 38.1 kg, at 105 months of age, were confined in collective stalls and fed (ad libitum) a diet containing 0, 50, 100, or 150 g/kg LC on a diet dry matter (DM) basis. Licuri cake inclusion induced quadratic responses ($P < 0.05$) in the intakes of DM (9.57 kg/day at 97.8 g/kg LC), crude protein (CP; 1.02 kg/day at 91.7 g/kg LC), and total digestible nutrients (6.68 kg/day at 75.2 g/kg LC). The digestibility of DM, CP, and non-fibrous carbohydrates decreased linearly ($P < 0.05$). Neutral detergent fiber (NDF) intake and rumination efficiencies increased linearly ($P < 0.05$) with the inclusion of LC in the diet. The inclusion of LC did not influence ($P > 0.05$) on daily weight gain, hot carcass weight, or back fat thickness in the carcass. Therefore, we recommend the inclusion of up to 150 g/kg LC in high-grain diets for feedlot cull cows.

Keywords Alternative feed · Non-forage fiber source · Oilseed by-product · *Syagrus coronata*

Introduction

The pandemic caused by SARS-Cov-2 changed the economic structure of markets around the world, especially for foods such as meat (Hashem et al., 2020). In the specific case of Brazil, the pandemic boosted the demand for beef, which led to an increased demand for feedlot-finishing as well as an increase in the price of grains used in animal diets (Futemma et al., 2021). In this context, the use of previously unattractive herd categories for feedlotting, such as cull cows, and the replacement of grains with agro-industrial by-products have become more sustainable alternatives for

this new scenario. Among the various by-products of the agroindustry, those obtained from oil extraction, such as oilseed cakes and meals, stand out.

Licuri cake (LC) is an oilseed by-product whose chemical composition includes (mean \pm standard deviation) 927.3 ± 38.6 g/kg dry matter, 238.2 ± 19.2 g/kg crude protein, 109.9 ± 29.1 g/kg ether extract, 473.9 ± 68.9 g/kg neutral detergent fiber, 173.1 ± 43.5 g/kg acid detergent lignin, and 89.4 ± 29.0 g/kg non-fibrous carbohydrates (Borja et al., 2014; Ferreira et al., 2017; Costa et al., 2019). The crude protein in LC is rich in neutral and acid detergent insoluble protein (Silva et al., 2015), and its ether extract is rich in short- and medium-chain fatty acids (Costa et al., 2018). Additionally, the neutral detergent fiber in LC is as effective as that of hay (Daza et al., 2021). Researchers who replaced soybean meal (the main dietary source of protein) with LC in the diet of sheep described a decrease in nutrient intake and digestibility, performance, and carcass traits (Santos et al., 2015; Costa et al., 2016). More recently, studies have suggested the possibility of including up to 100 g/kg LC in high-grain diets for steers and goat kids (Silva et al., 2020;

✉ Dorgival Moraes de Lima Júnior
juniorzootec@yahoo.com.br

¹ State University of Southwest Bahia, Itapetinga, BA 45700-000, Brazil

² Federal University of Bahia, Salvador, BA 41000-000, Brazil

³ Department of Animal Sciences, Federal Rural University of the Semi-Arid, Mossoro, Rio Grande do Norte 59625-900, Brazil

Silva et al., 2022). However, if we consider nutritional requirements as a major factor in the formulation of a diet, there exist recommendations for LC in diets for other animal categories, such as cull cows, especially in high-grain diets.

We hypothesize that the inclusion of up to 150 g/kg LC in high-grain diets for cull cows does not compromise animal performance. Therefore, the objective of this study was to examine the effect of including licuri cake in high-grain diets for cull cows on intake, digestibility, feeding behavior, weight gain, and carcass traits.

Materials and methods

Experimental location and animals

The experimental work of this study was carried out on Princesa do Mateiro farm, located in the municipality of Ribeirão do Largo, southwest region of the state of Bahia, Brazil (15°09'07" S, 40°15'32" W). The region is characterized by having a humid tropical climate, with average annual precipitation of 800 mm and an average annual temperature of 27 °C.

Forty Zebu beef cows with an average age of 108 months and an average live weight of 318 ± 38.17 kg were used. The cows were housed in collective stalls (10 animals/stall) with a partially covered, usable area of 100 m² (10 × 10 m) and 50 m² of cement floors. The stalls were equipped with covered feeders (10 linear meters) and concrete drinkers with a capacity of 250 L of water. All animals underwent a 15-day period of adaptation to the diets, stalls, and management, which was followed by 105 days of data collection, totaling 120 days of duration.

Management and experimental diets

At the beginning of the experimental period, the cows were identified with numbered plastic earrings and weighed. Soon afterwards, they were randomly distributed into four treatment groups in a completely randomized design with 10 replicates. The treatments consisted of a diet with the inclusion of 0 (control), 50, 100, or 150 g/kg of licuri cake (LC) in the diet DM.

The diets were formulated according to the NRC (1996) to meet the nutritional requirements of cows for a daily gain of 1.0 kg. The animals were fed fresh sugarcane bagasse and concentrate, at a roughage: concentrate ratio of 20:80 (Tables 1 and 2).

The animals received the diets ad libitum. Feed was supplied in two daily meals (60% of the total diet at 07 h 00 and 40% at 15 h 00), whose supply was adjusted every 3 days based on refusals, aiming at 10% ortos.

Table 1 Chemical composition of the feedstuffs used in the experimental diets (g/kg DM)

	Sugarcane bagasse	Licuri cake	Soybean meal	Ground sorghum
Dry matter ^a	196.0	835.0	820.2	862.8
Mineral matter ^b	84.4	25.9	63.4	9.2
Crude protein ^b	12.3	215.8	488.8	79.0
Ether extract ^b	6.5	119.7	27.1	30.3
NDFap ^{b,c}	774.6	627.7	154.8	124.7
NFC ^{b,d}	122.2	61.0	265.9	756.8
Lignin ^b	116.5	193.5	5.4	13.3
TDN ^{b,e}	420.1	578.0	796.4	868.3

^ag/kg as-is

^bg/kg dry matter

^cNeutral detergent fiber corrected for ash and protein

^dNon-fibrous carbohydrates

^eTotal digestible nutrients (Weiss, 1999)

Table 2 Ingredients and chemical composition of the supplied diets

	Licuri cake level (g/kg DM)			
	0	50	100	150
Proportion of ingredients (g/kg DM ^a)				
Sugarcane bagasse	200	200	200	200
Ground grain sorghum	693.3	667.2	640.5	623.3
Licuri cake	0.0	54.4	109.1	155.1
Soybean meal	84.2	57.0	28.6	0.0
Sodium bicarbonate	12.0	12.0	12.0	12.0
Mineral salt ^b	4.8	4.8	4.8	4.8
Limestone	5.8	5.4	5.1	4.8
Total	1000	1000	1000	1000
Chemical composition of diets (g/kg DM)				
Dry matter	687.9	694.7	693.7	697.0
Crude protein	107.1	106.2	107.1	104.1
Ether extract	25.2	29.0	44.1	46.2
NDFap ^b	276.4	347.3	377.9	413.3
iNDF ^d (%DM)	122.3	135.1	148.0	159.0
NFCap ^c	535.2	467.6	470.4	450.4
Lignin	46.6	61.6	74.6	85.2
TDN ^d	684.3	681.9	681.4	680.7
Metabolizable energy (Mcal/kg DM)				

^aDry matter

^bComposition: calcium 140 g; phosphorus 65 g; sodium 148 g; magnesium 5 g; sulfur 12 g; cobalt 107 mg; copper 1550 mg; iodine 150 mg; manganese 1400 mg; nickel 30 mg; selenium 18 mg; zinc 4500 mg; 1120 mg; fluoride (maximum) 650 mg

^cNeutral detergent fiber corrected for ash and protein

^dIndigestible neutral detergent fiber; on-fiber carbohydrates corrected for ash and protein, total digestible nutrients

Sampling and laboratory analysis of feed, orts, and feces

The ingredients were sampled at each blend of feed and later pooled into a composite sample per ingredient (soybean meal, ground sorghum, licuri cake). These were placed in plastic bags, which were then labeled and frozen at $-10\text{ }^{\circ}\text{C}$ for later chemical analysis.

Samples of feed (concentrate and roughage) and orts were pre-dried in a forced-air oven ($55\text{ }^{\circ}\text{C}$) until reaching constant weight and then ground in a Wiley mill (one portion through a 2-mm-mesh sieve and another through a 1-mm-mesh sieve). Fecal samples were pre-dried in a forced-air oven ($55\text{ }^{\circ}\text{C}$) until reaching constant weight and later ground in a Wiley mill with a 2-mm-mesh sieve. Subsequently, the samples were placed in hermetically sealed flasks and labeled for composition analysis.

Feed, orts, and fecal samples were analyzed for dry matter (DM; method INCT-CA G-003/1), mineral matter (MM; method INCT-CA M-001/1), crude protein (CP; method INCT-CA N-001/1), ether extract (EE; method INCT-CA G-004/1), neutral detergent fiber corrected for ash and protein (NDFap; methods INCT-CA F-002/1, INCT-CA M-002/1, and INCT-CA N-004/1), acid detergent fiber (ADF; method INCT-CA F-004/1), and lignin (method INCTCA F-005/1) contents, by techniques described by Detmann et al. (2012).

Non-fibrous carbohydrates (NFCs) were calculated using the formula below (Detmann and Valadares Filho, 2010):

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

where %CP = crude protein content, %EE = ether extract content, %MM = ash content, and %NDFap = neutral detergent fiber content corrected for ash and protein. Total digestible nutrients (TDN) were calculated according to the NRC (2000), as shown below:

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

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

Evaluation of intake and apparent digestibility

Individual daily DM intake was measured using indigestible neutral detergent fiber (iNDF), which was obtained after in situ incubation of samples of feed (supplied and orts) and feces in non-woven fabric bags ("TNT 100"; $5 \times 5\text{ cm}$) for 288 h (Detmann et al., 2012). The remaining material from incubation was washed in running water until it became transparent and subjected to extraction with

a neutral detergent solution. The residue was considered iNDF, as determined by the equation below:

$$\% \text{iNDF} = [(W3 - (W1 \times C1)) \times 100] / W2,$$

where W1 = bag tare, W2 = sample weight, W3 = weight after the extraction process, and C1 = blank bag correction factor (final weight of the bag after drying/original bag weight).

After obtaining iNDF, the following formula was used to determine the total individual dry matter intake (TDMI):

$$\text{TDMI}(\text{kg}/\text{day}) = (\text{FO} \times \text{iNDF}_{\text{Feces}}) / \text{iNDF}_{\text{diet}},$$

where FO = fecal output (kg/day), $\text{iNDF}_{\text{Feces}}$ = indigestible neutral detergent fiber in feces (kg), and $\text{iNDF}_{\text{Diet}}$ = indigestible neutral detergent fiber in the diet (kg). To estimate fecal output, chromic oxide (Cr_2O_3) was used as an external marker, which was supplied daily at 07 h 00, in a single dose of 10 g per animal. Chromic oxide was packed in paper cartridges that were given orally to the animals for a period of 12 days. The first 7 days were used for the animals to adapt to the management and regulation of the marker's excretion in the feces and the remaining 5 days to collect feces with the marker. Feces were collected directly in the stalls, once per day, at five pre-established times (08 h 00, 10 h 00, 12 h 00, 14 h 00, and 16 h 00). Collected samples were immediately frozen at $-10\text{ }^{\circ}\text{C}$. Composite samples were prepared for each animal, based on the pre-dried weight, and placed in hermetically sealed plastic bottles for later analysis.

The Cr_2O_3 analysis consisted of nitric-perchloric digestion followed by reading with an atomic absorption spectrophotometer (GBC Avanta Sigma) (Williams et al., 1962). Subsequently, fecal output was calculated by the following formula (Smith and Reid, 1995):

$$\text{FO} = \text{CO}_s / \text{CO}_F,$$

where FO = daily fecal output (g/day), CO_s = amount of chromic oxide supplied (g/day), and CO_F = concentration of chromic oxide in feces (g/g DM).

The apparent digestibility of the nutritional components was determined by the formula described by Silva and Leão (1979), as follows:

$$D = [(\text{nutrient intake, kg} - \text{nutrient output, kg}) / \text{nutrient intake, kg}] \times 100.$$

Evaluation of feeding behavior

Feeding behavior was evaluated in six 24-h periods of observation during the experiment, totaling 144 h of observation. The animals were identified with ribbons and evaluated visually by trained observers. During the night, flashlights

and electric light were used to facilitate visualization (the animals had been adapted to light).

For the behavioral assessment, the animals were observed at 5-min intervals (Silva et al., 2008). This resulted in 288 daily observations per animal, on each evaluation day. The following behavioral variables were studied: feeding time, rumination time, and time expended performing other activities (“idleness”). Behavioral activities were considered mutually exclusionary (Pardo et al., 2003).

On the same days, the cows were also observed in two periods of the day (morning and afternoon), in three replicates per period (Burger et al., 2000), to count the number of rumination chews per cud, i.e., the number of times a cud is chewed after being regurgitated. Cud rumination time (CRT, s/cud), that is, the time taken by the animal to chew each cud after regurgitating it, was determined. Both observations were made using digital stopwatches.

Total chewing time (TCT) and the number of cuds ruminated per day (NCR) were also calculated (Burger et al., 2000), as shown next:

$$\text{TCT} = \text{FT} + \text{RT},$$

where TCT: total chewing time (min), FT: feeding time (min), and RT: rumination time (min).

$$\text{NCR} = \text{RT}/\text{CRT}$$

where NCR: number of cuds ruminated (n/day), RT: rumination time (min/day), and CRT: cud rumination time (s/cud). Time series discretization was performed in electronic spreadsheets, by counting the discrete bouts of feeding, rumination, and other activities (Silva et al., 2008). The average duration of each discrete bout was determined by dividing the daily times spent on each activity by the number of discrete bouts of the same activity.

Voluntary intakes of DM and NDFap were considered in the evaluation of intake and rumination efficiencies, which were expressed in grams of DM and NDFap per time unit. The DM and NDF intake and rumination efficiencies were calculated by dividing the intake of the chemical component by feeding time (intake efficiency) or rumination time (rumination efficiency) (Burger et al., 2000).

Evaluation of animal performance and carcass traits

After a solid-feed deprivation period of 12 h, the animals were weighed at the beginning, 15 days into (period of adaptation to the diets), and at the end of the experimental period to measure weight gain and performance.

Average daily gain (ADG) was calculated as the difference between the final body weight and initial body weight divided by the experimental period (105 days). Feed efficiency (FE) was calculated as a function of the animals'

weight gain (kg/day) and DMI intake (kg/day), using the equation below:

$$\text{FE} = (\text{ADG}/\text{DMI})$$

where ADG = average daily gain in kg, and DMI = total daily dry matter intake, in kg.

At the end of the experiment, the animals were slaughtered in a commercial slaughterhouse in the region in accordance with the norms established by Normative Instruction no. 3, of January 17, 2000, of the Ministry of Agriculture, Livestock and Supply. The carcass of each animal was identified and sawn lengthwise along the sternum and vertebral spine, originating two similar halves, which were weighed to determine the hot carcass weight (HCW). Hot carcass yield (HCY) was determined by the ratio between hot carcass weight and final body weight (FBW) (Gomes et al., 2021), as follows:

$$\text{HCY} = (\text{HCW}/\text{FBW}) \times 100.$$

In the slaughterhouse, a transverse section was made between the 12th and 13th ribs on the right carcass half, exposing the longissimus dorsi muscle. Ribeye area was measured by the grid-pattern method. “Ratio,” a measurement that characterizes the ratio between the height and width of the *longissimus dorsi* muscle (obtained using a graduated ruler), was also determined. Back fat thickness was expressed as the arithmetic mean of three measurements made in the *Longissimus dorsi* muscle region, using a caliper (Gomes et al., 2021).

Statistical analysis

Results were interpreted statistically by variance and regression analysis, using the System for Statistical and Genetic Analysis (SAEG). The criteria adopted for choosing the model were the coefficient of determination (calculated as the ratio between the sum of squares of the regression and the sum of squares of treatments) and the observed significance of the regression coefficients, using the F test, according to the following model:

$$Y_{ijk} = m + T_i + e_{ijk}$$

where Y_{ijk} = observed value of the variable, m = general constant, T_i = effect of treatment i , and e_{ijk} = error associated with each observation.

Results

Dietary inclusion of LC increased ($P < 0.01$) the cows' DM intake up to the level of 97.8 g/kg, after which point it declined. Crude protein intake was highest (1.02 kg/

day) when the cows consumed a diet with approximately 91.7 g/kg LC (Table 3).

The intakes of EE and NDF increased linearly ($P < 0.01$) with the inclusion of LC in the diet. Maximum TDN intake (6.68 kg/day) was achieved at 75.2 g/kg of LC in the diet. The apparent digestibility of DM, CP, and NFC decreased

linearly ($P < 0.05$). Neutral detergent fiber digestibility was highest at 48.5 g/kg LC in the diet.

Dietary inclusion of LC did not influence ($P > 0.05$) feeding or rumination times. However, NDF intake and rumination per time unit were increased ($P < 0.05$) (Table 4).

Table 3 Nutrient intake and digestibility in cull cows fed high-grain diets with licuri cake

	Licuri cake level (g/kg DM)				SEM	P-value ²	
	0	50	100	150		L	Q
Intake							
Dry matter (kg/day)	8.06	9.41	9.38	9.22	0.15	0.006	0.006 ^a
Dry matter (%BW)	2.21	2.48	2.55	2.38	0.04	0.051	0.001 ^b
Crude protein (kg/day)	0.86	1.00	1.00	0.96	0.01	0.222	< 0.001 ^c
Ether extract (kg/day)	0.20	0.28	0.41	0.43	0.01	< 0.001 ^d	0.004
NDFap (kg/day)	2.23	3.27	3.54	3.81	0.10	< 0.001 ^e	< 0.001
NDFap (%BW)	0.60	0.86	0.96	0.97	0.02	< 0.001 ^f	< 0.001
NFC (kg/day)	4.31	4.4	4.41	4.15	0.05	0.470	0.106
TDN (kg/day)	5.51	6.42	6.39	6.26	0.10	0.006	0.004 ^g
Digestibility (g/kg)¹							
Dry matter	766.9	747.0	726.4	717.5	0.92	0.000 ^h	0.463
Crude protein	742.6	701.0	672.4	653.9	0.63	0.000 ⁱ	0.123
Ether extract	669.3	677.3	673.1	704.7	1.01	0.270	0.807
NDFap	496.4	551.9	523.3	496.7	0.79	0.904	0.008 ^j
NFC	770.1	739.0	739.6	731.5	0.57	0.023 ^k	0.296

NDFap neutral detergent fiber corrected for ash and protein, NFC non-fibrous carbohydrates, TDN total digestible nutrients

¹SEM standard error of the mean

²Significant probabilities at the 5% level for the linear or quadratic model

Regression equations: ^a $y = -0.0151x^2 + 0.2955x + 8.1225$, $R^2 = 0.9372$; ^b $y = -0.0044x^2 + 0.0776x + 2.208$, $R^2 = 0.9988$; ^c $y = -0.0018x^2 + 0.033x + 0.865$, $R^2 = 0.9618$; ^d $y = 0.0164x + 0.207$, $R^2 = 0.9391$; ^e $y = 0.1002x + 2.461$, $R^2 = 0.8759$; ^f $y = 0.0242x + 0.0666$, $R^2 = 0.8218$; ^g $y = -0.0002x^2 + 0.0301x + 5.5534$, $R^2 = 0.9336$; ^h $y = -0.506x + 764.64$, $R^2 = 0.9717$; ⁱ $y = -0.884x + 736.45$, $R^2 = 0.9678$; ^j $y = -0.018x^2 + 1.748x + 500.86$, $R^2 = 0.8151$; ^k $y = -0.345x + 762.23$, $R^2 = 0.7533$

Table 4 Feeding behavior of cull cows fed high-grain diets with licuri cake

	Licuri cake level (g/kg DM)				SEM	P-value ¹	
	0	50	100	150		L	Q
Feeding time (min/day)	215.5	233.0	255.9	240.5	8.83	0.228	0.457
Rumination time (min/day)	110.0	115.0	129.0	134.5	5.49	0.081	1.000
Idle time (min/day)	1114.5	1092.0	1055.0	1065.0	10.81	0.057	0.606
Total chewing time (min/day)	325.5	348.0	385.0	375.0	10.81	0.057	0.606
Intake efficiency (g DM/h)	2316.2	2599.4	2383.9	2471.9	103.48	0.976	0.892
Intake efficiency (g NDF/h)	639.3	903.0	899.9	1020.6	43.01	0.002 ^a	0.464
Rumination efficiency (g DM/h)	4816.8	5188.9	4745.4	4428.6	199.50	0.503	0.555
Rumination efficiency (g NDF/h)	1329.8	1804.1	1792.6	1826.2	75.66	0.026 ^b	0.125
Number of cuds ruminated (n/day)	122.1	124.9	124.5	144.8	6.56	0.295	0.745
Number of chews per cud (n/day)	65.9	45.2	67.0	59.2	3.10	1.000	0.335
Chewing time per cud (s/cud)	60.8	56.1	63.2	55.7	1.68	0.808	0.905

SEM standard error of the mean

¹Significant probabilities at the 5% level for the linear or quadratic model

Regression equations: ^a $y = 3.423x + 695.43$, $R^2 = 0.8348$; ^b $y = 4.4229x + 1468.2$, $R^2 = 0.6311$

The inclusion of LC in the diet did not influence ($P > 0.05$) the final weight (437.3 kg), average daily gain (1.1 kg/day), hot carcass weight (210.9 kg), or back fat thickness (3.16 mm) of the cows (Table 5).

Discussion

The increased dietary levels of NDFap provided by the inclusion of LC likely favored DM intake by the cows by improving their rumen environment, which is especially the case in high-grain diets. Diets with higher NDF contents result in more chewing (see upward trend in chewing time) and, consequently, more saliva in the rumen-reticulum to regulate the pH of this compartment (Souza et al., 2022). In this context, Daza et al. (2021) reported that the physically effective NDF (peNDF1.18) content of licuri is similar to that of Tifton 85 hay, and that including the former ingredient in the diet increases its peNDF level. Furthermore, for cows whose DM intake is regulated by the diet's energy density (i.e., in high-grain diets), increasing the dietary peNDF may favor DM intake (Zebeli et al., 2011).

Even with the total replacement of soybean meal with LC, the CP intake of the cows was higher at the inclusion of around 90 g/kg LC in the diet. In non-pregnant cows, the metabolizable protein requirement is low and easily met by microbial protein (Gionbelli et al., 2016). Therefore, in diets in which energy is not a limiting factor (e.g., high-grain diets), the inclusion of an ingredient with lower protein quality (LC) relative to soybean meal does not negatively influence the animals' CP intake (Silva et al., 2014). In contrast, Costa et al. (2016) observed a linear decrease in the CP intake of lambs fed diets with increasing levels of LC.

The increased intake of EE and NDF is explained by the higher levels of these analytical fractions in the experimental diets containing LC. In general, the inclusion of by-products

of oil palms (African oil palm, licuri, babassu, and coconut) in ruminant diets increases the intake of EE and NDF (Oliveira et al. 2012). Additionally, we can attribute the greater TDN intake of the cows (up to the LC level of 75 g/kg) to the increased intake of EE and digestible NDF. Licuri cake inclusion in the animal diet will usually reduce TDN intake (Costa et al., 2016; Silva et al., 2020).

Dry matter digestibility decreased following the inclusion of LC, which was possibly due to the increased intake of NDF (rich in lignin) by the cows. The presence of LC likely reduced the rate of ruminal disappearance of DM, as a result of the decreased rate of degradation (kd) of this fraction (Silva et al., 2015). In addition to the reduced degradation of DM, the lower digestibility of CP can also be attributed to a lower CP degradation rate in the diets containing LC. This by-product is rich in NDIP and ADIN, fractions of low or no rumen degradability (Oliveira et al., 2012), which probably impaired the digestibility of CP from the diets with LC. Borja et al. (2014) reported a linear decrease in plasma urea nitrogen in goats fed LC and attributed this finding to the increase in fractions B3 and C of total nitrogen in the diet, following the inclusion of LC.

The observed reduction of NFC digestibility is in consequence of the decreasing levels of NFC in the experimental diets. When the proportion of sorghum grain in the diet is reduced, the amount of starch available for bacterial fermentation and digestion in cows is also reduced, which leads to a lower apparent digestibility of starch in the total tract (Moharrery et al., 2014). Ferreira et al. (2017) also described a decrease in the digestibility of dietary NFC by cows fed diets with increasing levels of LC.

Dietary inclusion of LC increased the NDF intake and rumination efficiencies, possibly due to the altered physical nature of the diets and the tendency for rumination time to increase. Licuri cake inclusion increased the NDF content of the experimental diets, thereby increasing the intake

Table 5 Performance and carcass traits of cull cows fed high-grain diets with licuri cake

	Licuri cake level (g/kg DM)				SEM	P-value ^a	
	0	50	100	150		L	Q
Initial weight (kg)	314.9	317.0	316.9	327.3	–	–	–
Final weight (kg)	426.0	443.1	422.7	457.5	6.62	0.193	0.704
ADG (kg/day) ^b	1.1	1.2	1.0	1.2	0.05	0.633	0.901
Feed efficiency	0.13	0.13	0.11	0.14	1.06	0.443	1.000
Hot carcass weight (kg)	208.60	209.18	206.36	219.49	3.07	0.328	0.390
Hot carcass yield (%)	49.51	47.78	48.95	48.78	0.12	0.995	0.837
Back fat thickness (mm)	2.75	3.94	2.68	3.26	0.12	0.957	0.149
Ribeye area (cm ²)	57.30	53.90	58.59	59.31	1.35	0.518	0.653
Ratio	0.50	0.50	0.53	0.57	0.01	0.100	0.824

SEM standard error of the mean

^aSignificant probabilities at the 5% level for the linear or quadratic model

^bAverage daily gain

and rumination of NDF by the cows. At the same time, the presence of LC (also rich in EE) made the diets less powdery and more aggregate, favoring an increase in bite size. In other words, we speculate that the cows fed LC ate and ruminated larger cuds that were also richer in NDF, without changing the time spent per cud. Bagaldo et al. (2019) also reported increases in rumination time and NDF rumination efficiency in lambs that received supplement with increasing LC contents.

Partial replacement of grain sorghum and full replacement of soybean meal with LC in the diet did not influence the final weight or ADG of the cows. Thus, the formulation of complete diets containing LC (up to 150 g/kg) met the nutritional requirements of cull cows without negatively affecting their weight gain or final weight. However, in more demanding animals, such as growing calves, increasing levels of LC in the diet reduced final weight and ADG (Silva et al., 2022). Therefore, caution should be exercised when including this by-product.

The similar performance of the groups was likely due to the lack of effects of LC on hot carcass weight and yield. Conversely, Santos et al. (2015) and Silva et al. (2020) observed a decrease in the HCW of lambs and goats, respectively, using high-grain diets with increasing levels of LC. It should be noted that the average HCW found in our study was 49%, which is considered high for cull cows. We suggest that the high-grain diet allowed for the production of carcasses with a higher degree of fatness.

Conclusion

Licuri cake increases nutrient intake but does not influence the feeding behavior or performance of feedlot cull cows. We recommend including 150 g/kg licuri cake in high-grain diets for feedlot cull cows.

Thus, the formulation of complete diets containing LC (up to 150 g/kg) met the nutritional requirements of cull cows without negatively affecting their final weight.

Acknowledgements Thanks are due to the Coordination for the Improvement of Higher Education Personnel — CAPES, for the Master's fellowship grant.

Author contribution All the authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by L.V. Santos, R.R. Silva, F.F. da Silva, T.R. Paixão, M.C. Santos, A.S. Danieletto, T.C.S. Mandinga, A.P.G. Silva, G.G.P. Carvalho, and D.M. Lima Júnior. The first draft of the manuscript was written by L.V. Santos, R.R. Silva, F.F. da Silva, T.R. Paixão, M.C. Santos, A.S. Danieletto, T.C.S. Mandinga, A.P.G. Silva, G.G.P. Carvalho, and D.M. Lima Júnior. All the authors commented on previous versions of the manuscript. All the authors read and approved the final manuscript.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Ethics approval This study was approved by the Animal Use Ethics Committee (CEUA) at the State University of Southwest Bahia, located in Itapetinga—BA, Brazil (approval no. 147/2017).

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare competing interests.

References

- Bagaldo, A.R., Miranda, G.S., Soares Júnior, M.S.F., Araújo, F.L., Matoso, R.V.M., Chizzotti, M., Bezerra, L., and Oliveira, R.L., 2019. Effect of Licuri cake supplementation on performance, digestibility, ingestive behavior, carcass traits and meat quality of grazing lambs, *Small Ruminant Research*, 177, 18--24.
- Borja, M., Oliveira, R.L., Bagaldo, A.R., Pereira, M.L.A., Portela, R.W., Barbosa, A.M., Vaz, C.R.D.M., and Carvalho, G.G.P., 2014. Microbial protein and blood parameters of goats fed with licuri cake, *Semina: Ciências Agrárias*, 14, 519--529.
- Burger, P.J., Pereira, J.C., Queiroz, A.C., Silva, J.F.C., Valadares Filho, S.C., Cecom, P.R., and Casali, A.D.P., 2000. Comportamento ingestivo de bezerros holandeses alimentados com dietas contendo diferentes níveis de concentrado, *Revista Brasileira de Zootecnia*, 29, 236--242.
- Costa, J.B., Oliveira, R.L., Silva, T.M., Ribeiro, R.D.X., Silva, A.M., Leão, A.G., and Rocha, T.C., 2016. Intake, digestibility, nitrogen balance, performance, and carcass yield of lambs fed licuri cake, *Journal of Animal Science*, 94, 2973--2980.
- Costa, J.B., Oliveira, R.L., Silva, T.M., Barbosa, A.M., Borja, M.S., Pellegrini, C.B., Oliveira, V.S., Ribeiro, R.D.X., and Bezerra, L.R., 2018. Fatty acid, physicochemical composition and sensory attributes of meat from lambs fed diets containing licuri cake, *Plos One*, 13, e0206863.
- Costa, J.B., Oliveira, R.L., Silva, T.M., Ribeiro, O.L., Ribeiro, R.D.X., Pinto, L.F.B., and Nascimento, T.V.C., 2019. Economic analysis of the finishing of lambs under confinement conditions using licuri cake (*Syagrus coronata* Mart. Becc.), *Revista Brasileira de Saúde e Produção Animal*, 20, e0252019.
- Daza, A., Souza, J.G., Monnerat, J.P.I.S., and Ribeiro, C.V.D.M., 2021. Performance of growing lambs supplemented with ground licuri (*Syagrus coronata*), *Animal Bioscience*, 34, 1014--1021.
- Detmann, E., Souza, M.A., Valadares Filho, S.C., Queiroz, A.C., Berchielli, T.T., Saliba, E.O.S., Cabral, L.S., Pina, D.S., Ladeira, M.M., and Azevedo, J.A.G., 2012. Métodos para análises de alimentos - INCT - Ciência Animal (Editora UFV, Viçosa).
- Detmann, E., and Valadares Filho, S.C., 2010. On the estimation of non-fibrous carbohydrates in feeds and diets, *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, 62, 980--984.
- Ferreira, A.C., Vieira, J.F., Barbosa, A.M., Silva, T.M., Bezerra, L.R., Nascimento Júnior, N.G., Freitas Júnior, J.E., Jaeger, S.M.P.L., Oliveira, P.A., and Oliveira, R.L., 2017. Effect of replacing ground corn and soybean meal with licuri cake on the performance, digestibility, nitrogen metabolism and ingestive behavior in lactating dairy cows, *Animal*, 11, 1957--1965.

- Futemma, C., Tourne, D.C.M., Andrade, F.A.V., Santos, M.N., Macedo, G.S.S.R., and Pereira, M.E., 2021. A pandemia da Covid-19 e os pequenos produtores rurais: superar ou sucumbir?, *Ciências Humanas*, 16, 1-18.
- Gionbelli, M.P., Valadares Filho, S.C., and Duarte, M.S., 2016. Exigências nutricionais para vacas de corte vazias e gestantes. In: Valadares Filho, S.C., Silva, L.F.C., Gionbelli, M.P., Rotta, P.P., Marcondes, M.I., Chizzotti, M.L., and Prados, L.F., (eds). *BR-Corte: Tabela Brasileira de Exigências Nutricionais*. (Editora UFV, Viçosa).
- Gomes, M.N.B., Feijó, G.L.D., Duarte, M.T., Silva, L.G.P., Surita, L.M.A. and Pereira, M.W.F. 2021. Beef carcass assessment manual. (Editora UFMS, Campo Grande, MS).
- Hashem, N.M., González-Bulnes, A., and Rodriguez-Morales, A.J.R., 2020. Animal Welfare and Livestock Supply Chain Sustainability Under the COVID-19 Outbreak: An Overview, *Frontier Veterinary Science*, 7, 582528.
- Moharrery, A., Larsen, M., and Weisbjerg, M.R., 2014. Starch digestion in the rumen, small intestine, and hind gut of dairy cows—a meta-analysis, *Animal Feed Science and Technology*, 192, 1--14.
- National Research Council NRC, 1996. Nutrient of requirements of Beef cattle (Washington, D.C.).
- National Research Council NRC, 2000. Nutrient of requirements of Beef cattle (Washington, D.C.).
- Oliveira, R.L., Leão, A.G., Ribeiro, O.L., Borja, M.S., Pinheiro, A.A., Olivera, R.L., and Santana, M.C.A., 2012. Biodiesel industry by-products used for ruminant feed, *Revista Colombiana de Ciencias Pecuarias*, 25, 625--638. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120-06902012000400011
- Pardo, R.M.P., Fischer, V., Balbinotti, M., Moreno, C.B., Ferreira, E.X., Vinhas, R.I., and Monks, P.L., 2003. Comportamento ingestivo diurno de novilhos em pastejo a níveis crescentes de suplementação energética, *Revista Brasileira de Zootecnia*, 32, 1408--1418.
- Santos, F.M., Santos, J.D.R., Carvalho, F.A.L., Queiroz, M.A.A., Yamamoto, S.M., and Guimarães, O.D., 2015. Licury cake in lamb feed: characteristics of carcass and non-carcass components, *Animal Science and Veterinary*, 39, 260--268.
- Silva, R.R., Prado, I.N., Carvalho, G.G.P., Santana Júnior, H.A., Silva, F.F., and Dias, D.L.S., 2008. Efeito da utilização de três intervalos de observações sobre a precisão dos resultados obtidos no estudo do comportamento ingestivo de vacas leiteiras em pastejo, *Revista Ciência Animal Brasileira*, 9, 319--326.
- Silva, M.A., Oliveira, R.L., Ribeiro, O.L., Bagaldo, A.R., Bezerra, L.R., Carvalho, S.T., Abreu, C.L., and Leão, A.G., 2014. Valor nutricional de resíduos da agroindústria para alimentação de ruminantes, *Comunicata Scientiae*, 5, 370--379.
- Silva, A.L., Marcondes, M.I., Veloso, C.M., Sousa, F.C., and Knupp, L.S., 2015. Simulation of rumen fermentation kinetics of by-products from the biodiesel industry with in vitro gas production technique, *Semina: Ciências Agrárias*, 15, 3851--3861.
- Silva, W.P., Santos, S., Cirne, L.G.A., Pina, D.S., Alba, H.D.R., Rodrigues, T.C.G.C., Araújo, M.L.G.M. L., Lima, V.G.O., Galvão, J.M., Nascimento, C.O., Rodrigues, C.S., and Carvalho, G.G.P., 2020. Carcass characteristics and meat quality of feedlot goat kids fed high-concentrate diets with licury cake, *Livestock Science*, 244, 104391.
- Silva, L.F., Barbosa, A.M., Silva Júnior, J.M., Oliveira, V.S., Silva, T.M., Gouveia, A.A., Lima, A.G.V.O., Nascimento, T., Bezerra, L., and Oliveira, R.L., 2022. Growth, physicochemical properties, fatty acid composition and sensorial attributes from longissimus lumborum of young bulls fed diets with containing licuri cake, *Livestock Science*, 255, 104775.
- Silva, J.F.C., and Leão, M.I., 1979. Fundamentos de nutrição dos ruminantes, (Piracicaba, SP).
- Smith, A.M., and Reid, J.T., 1995. Use of chromic oxide as an indicator of fecal output for the purpose of determining the intake of a pasture herbage by grazing cows, *Journal Dairy Science*, 38, 515--524.
- Souza, J.G., Ribeiro, C.V.D.M., and Harvatine, K.J., 2022. Meta-analysis of rumination behavior and its relationship with milk and milk fat production, rumen pH, and total-tract digestibility in lactating dairy cows, *Journal of Dairy Science*, 105, 188--200.
- Weiss, W.P., 1999. Energy prediction equations for ruminant feeds. In: *Cornell Nutrition Conference For Feed Manufacturers*, 61, 176-185.
- Williams, C.H., David, D.J., Iismaa, O., 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry, *Journal of Agricultural Sciences*, 59, 381--385.
- Zebeli, Q., Aschenbach, J.R., Tafaj, M., Boguhn, J., Ametaj, B.N., and Drochner, W., 2011. Role of physically effective fiber and estimation of dietary fiber adequacy in high-producing dairy cattle, *Journal Dairy Science*, 95, 1041--1056.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.